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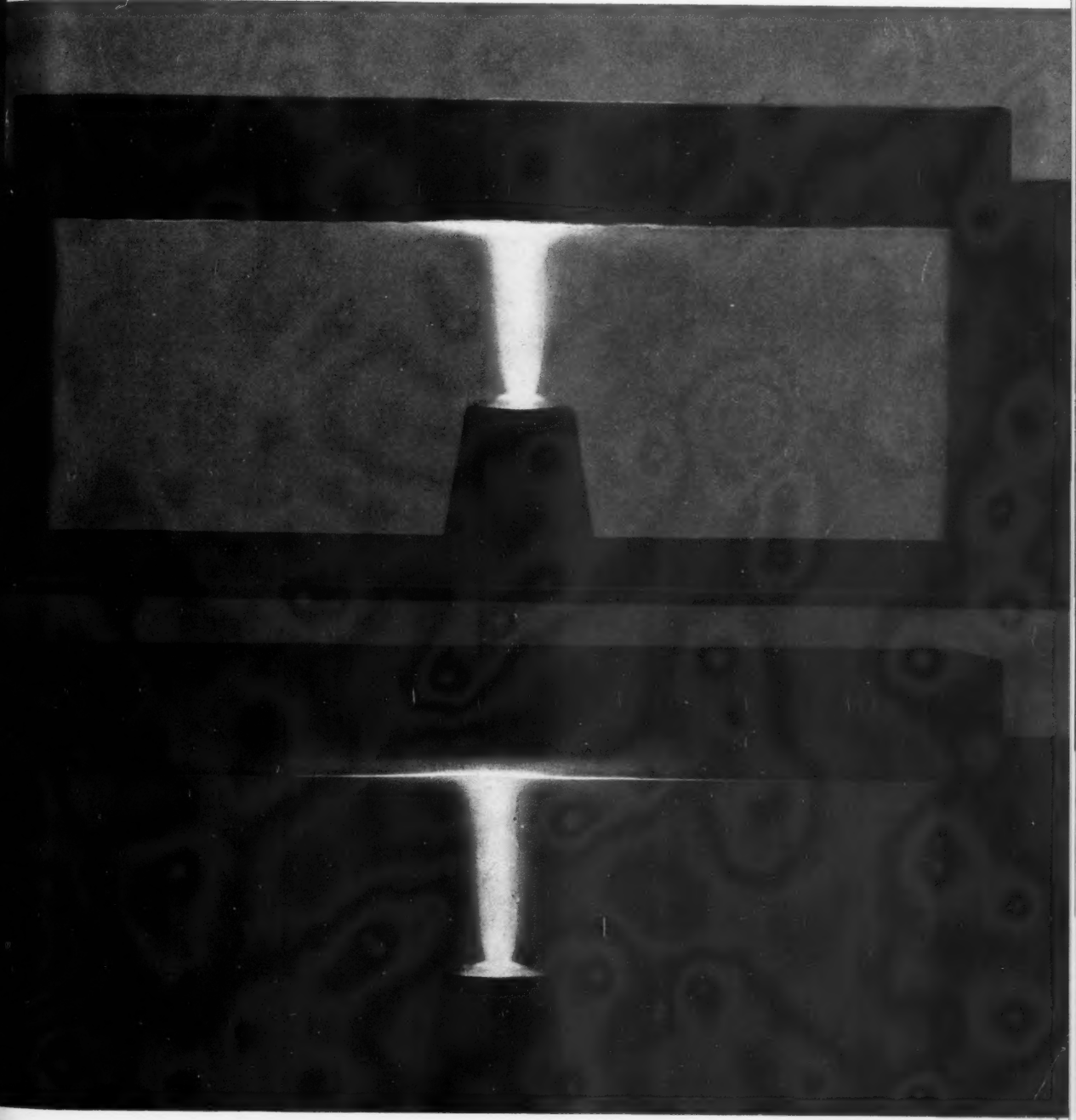
AUGUST 1961



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Solids for Space Vehicles . . . . William Cohen
The Pluto Program . . . . . Harry L. Reynolds
Low-Power Nuclear Rockets . . . . Ralph S. Cooper

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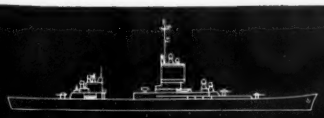

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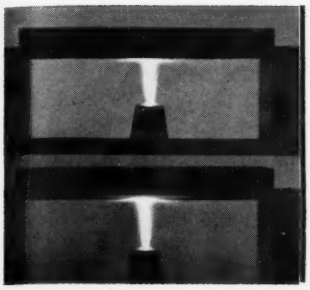

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Astronautics

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Vol. 6 No. 8 August 1961

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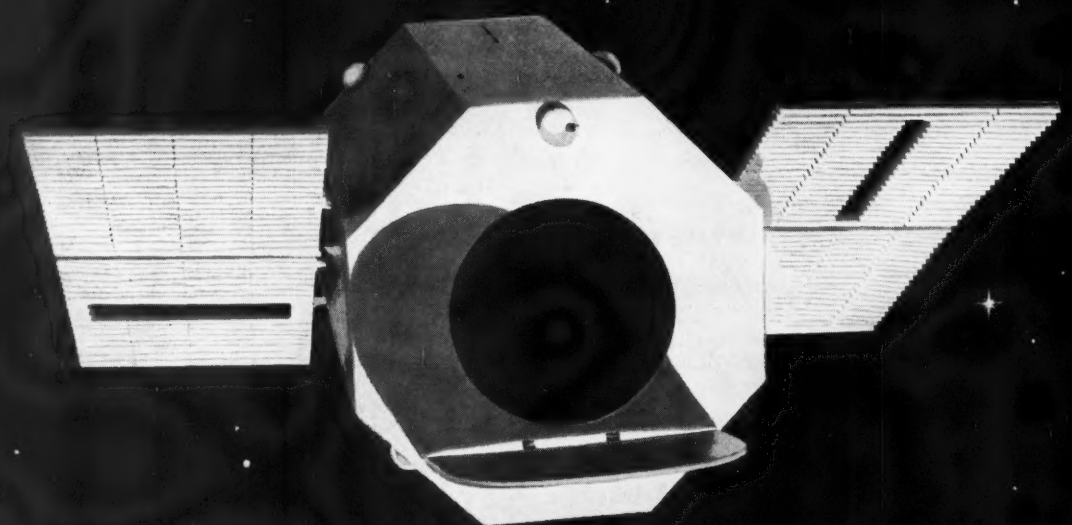
How advanced ideas grow into reality at



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THIRD: complete research and test facilities—Grumman's already extensive aero-space facilities were further expanded in 1960 by a new 5-million-dollar Electronics Systems Center which houses some of the most advanced equipment in the country. A major space environmental installation is also currently under way.

FOURTH: continuing space studies—For many months Grumman scientists and engineers have carried on extensive studies in such fields as stabilization and control, data processing, plasma physics, magnetohydrodynamics, hypersonic aerodynamics and related fields, to complement the company's outer space programs.

These four areas comprise Grumman's competence in transforming ideas into reality. This ability is being demonstrated in the Orbiting Astronomical Observatory (OAO) shown at left in an artist's impression. Conceived by Goddard Space Flight Center of National Aeronautics and Space Administration, and now under development by Grumman, the OAO will be used to study the unknowns of ultraviolet radiation from the stars . . . the life history of stars . . . the origins of the universe. Launching date: 1963. Grumman Aircraft Engineering Corporation, Bethpage, Long Island, N. Y.

Advanced ideas grow into reality at . . .

Grumman

Astro notes

LUNAR PROGRAM

• Responding to President Kennedy's request for a sharply stepped-up space program, the Senate Committee on Aeronautical and Space Sciences voted unanimously to authorize NASA the total amount requested for fiscal 1962: $1,784,300,000. This amount includes an initial installment of $549 million to tool up for the lunar-landing program. Committee Chairman Robert Kerr, D—Okla., expressed confidence that "the people will support the investments needed to insure continuation of this nation's over-all lead" in space.

• NASA maintained silence on an expected reorganization for the lunar effort. This reorganization might see a new Headquarters office with top-to-bottom direction of the lunar program, possibly including direct control of the proposed $60-million manned space laboratory and the NASA-Marshall SFC. Within NASA, the strongest contender for the head of this office looked like Wernher von Braun. But space agency officials insisted they are also looking outside NASA for potential candidates.

• Though organization details remained obscure Maj. Gen. Don R. Ostrander, NASA Chief of Launch Vehicle Programs, was able to chart a course for development of the Nova propulsion hardware required for a lunar expedition. NASA will place the Nova vehicle and facilities design contracts as promptly as possible, he said, and will establish an industrial production base concurrent with vehicle development to avoid delays. But its most dramatic steps will center on the two big liquid-propellant motors now under development at Rocketdyne Div. of North American Aviation.

• These are the J-2 lox-hydrogen unit of 200,000-lb thrust and the F-1 lox-kerosene monster of 1.5-million-lb thrust. Ostrander said NASA will order two-shift operation of the F-1 test facilities, initiate follow-on development programs for both the F-1 and J-2, accelerate production and delivery of engines required for actual vehicle installation (the first J-2 is to be delivered in Oct. 1962), and build additional facilities to support the quickened programs.

• The keystone decision in the Nova program—whether it will use Pentagon-developed solid motors or clusters of NASA's liquid F-1—will not be made until 1964, the Senate Space Committee was advised. And although witnesses solemnly declared that one or the other program would be wiped out completely, there were already signs that this would be a hard trick to turn. Whether or not Nova uses the F-1, NASA already plans to incorporate the motor in a brand new C-3 version of Saturn. This will require a new first stage (S-IB) of 3-million-lb thrust. This Saturn C-3 would be capable of placing 100,000 lb in a low earth orbit or 24,000 lb in an escape trajectory. It would be able to place the Apollo three-man spacecraft in a lunar orbit and then return it to earth, while the C-2 Saturn is only marginally capable of a single circumlunar sweep.

• Decision to push for the C-3 probably will mean abandonment of the C-2 Saturn. The orbiting Apollo-A missions would continue to be assigned to the two-stage C-1 Saturn, with the C-3 picking up circumlunar and lunar-orbit assignments and the Nova handling the lunar landing.

• The proposed C-3 is also important as a hedge against possible public and congressional disenchantment over the enormous costs of the Nova vehicle. In the event Nova loses support, NASA can turn to the C-3 and orbital-rendezvous techniques to accomplish the landing mission. In addition, C-3's thrust of 3-million lb has frequently been mentioned as the minimum requirement for extensive manned space missions using nuclear upper stages.

• With its vast new vehicle projects, NASA's Marshall Space Flight Center is now anxious to get rid of its biggest project—the S-I stage of the Saturn. The 1.5-million-lb-thrust cluster of eight Rocketdyne H-1 engines will be transferred to an industrial firm by early 1962, according to the present plan. The supplemental budget request includes funds for planning, modification of facilities, tooling, and actual production of the S-I by an industrial contractor commencing with the first operational flight.

MAN IN SPACE

• NASA scheduled an Apollo briefing at Space Task Group headquarters, Langley AFB, Va., on August 1 for all prime contractors interested in submitting bids for the three-man spacecraft. Information on the Apollo requirement was to be assembled in Washington in mid-July at a three-day Apollo conference attended by STG, representatives from other NASA research centers, and the three Apollo study contractors—Martin, General Electric, and GD/Astronautics. Industry would have 60–90 days to prepare proposals following the Langley conference, with a contractor selection to take place about Jan. 1962.

• Though the suborbital phase of the Mercury program captured the headlines, the orbital Mercury wasn't forgotten. As a result of troubles in pinpointing the programmer malfunction in the Mercury-Atlas 3 shot in April, Convair ran into delays in shipping the MA-4 booster to Cape Canaveral. This means MA-4 will slip back to September and that STG's hopes of orbiting an American astronaut this year are practically dead.

• The reason for this is that STG requires an average of 6–8 weeks to prepare an Atlas for firing once it is delivered. Since NASA will insist on a minimum of two successful unmanned shots before attempting the manned flight, Jan. 1962 now looks like the earliest date barring further Atlas difficulties.

• Despite a succession of mechanical difficulties, AF Maj. Robert White set a new record of 3603 mph in the X-15 at Edwards AFB, Calif. A pressure loss produced a short-lived vapor cloud in the cockpit and inflated White's spacesuit, so that he was practically immobilized during a critical period of the flight. White and two other X-15 test pilots—North American's Scott Crossfield and NASA's Joe Walker—were awarded the Harmon Trophy for their piloting feats in 1960 aboard the X-15.

• NASA plans an operational test of the worldwide Mercury tracking network in late summer, using a 100-lb Scout payload carrying the same radar beacon and telemetry equipment as for the Mercury capsule. The flight will test each

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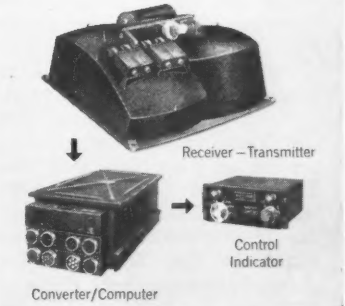

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tracking station's ability to detect, receive, and process Mercury data, as well as its ability to relay data to the NASA-Goddard Computing Center near Washington and the Mercury Control Center at Cape Canaveral. The communications package will be placed in a 300-mi. orbit with the same inclination planned for the Mercury capsule and will be available for repeated tests of the Mercury tracking network. Satellite contractors are Aeronutronic and McDonnell.

SATELLITES

• July opened with three dramatically successful satellite launches representing a broad area of technology. Discoverer XXVI, carrying a 300-lb capsule with experimental reconnaissance-satellite equipment, launched into orbit aboard Agena-B on July 7 and was caught in mid-air off Hawaii two days later. On July 12, Tiros III and Midas III satellites orbited aboard Thor-Delta and Atlas Agena-B, respectively. Tiros III, carrying two wide-angle TV cameras, immediately demonstrated again the great promise of meteorological satellites by spotting a hurricane forming in the Atlantic. The 3500-lb Midas III, bearing infrared detection equipment for spotting missile launches on the ground, attained a very high (1850-mi.) and nearly perfect circular polar orbit, which soon carried it over Russia.

• With the Tiros and Midas launches on July 12, the U.S. had 28 satellites in earth orbit. Since Explorer I was launched Jan. 31, 1958, we have launched 45 earth satellites successfully. It is an age, literally an age, since people were talking about Vanguard in 1955.

• The U.S. blazed a major space precedent when it resumed the Cuban over-flight trajectory with the Transit IV-A and included the 5-lb Snap radioisotope battery in the payload. Launches across Cuba and South America had been suspended since last November, when Transit III-A fell on Cuba and created an international incident. The Plutonium-238 battery was added to the Transit payload shortly before the flight at the insistence of the AEC and the Pentagon. With nuclear devices of ever-increasing size scheduled for launching from Cape Canaveral (culminating in nuclear-powered rockets), these agencies wanted to establish a hard-nosed U.S. policy, and they succeeded in overriding the objections of the State Dept.

• Washington officials steadfastly denied that this precedent was a primary objective of the shot. But it developed that there was little technical necessity for placing the Snap aboard the Transit or for launching the Transit across Cuba. The Navy admitted it has abandoned its original plan for 22- and 67-deg inclinations for the operational system of four Transits and has decided instead to place all of them in polar orbits beginning next year. And the Midas III flight from Point Arguello on July 12 could easily have carried the Snap without launching it across inhabited territory if the U.S. were really anxious to avoid this.

• In addition to the 175-lb Transit IV-A, which carried an improved memory system, the Thor-Able-Star launching rocket orbited two hitchhikers—James Van Allen's 40-lb Injun to measure radiation-belt phenomena and Herbert Friedman's 55-lb Greb equipped with two X-ray detectors to map solar radiation. They were placed in a nearly circular orbit with a perigee of 550 st. mi., an apogee of 629 mi., and a period of 104 min. Unfortunately, the two scientific satellites failed to separate from each other, and their usefulness was correspondingly diminished.

• NASA failed in an attempt to launch its S-55 micrometeoroid satellite in a Scout firing from Wallops Island. The 125-lb payload represented the most elaborate micrometeorite experiment yet attempted by the U.S. Instruments included 160 pressurized cells mounted on the fourth-stage rocket, 60 foil-gauge detectors, 46 wire-grid detectors, two cadmium-cell detectors and several piezo-electric crystal impact-detectors. The failure to attain orbit was traced to the third stage of the rocket, which did not ignite. It was Scout's second miss on three orbital tries.

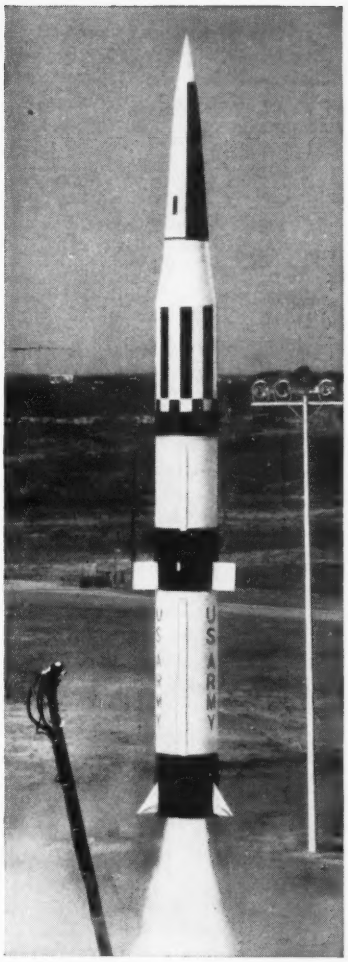
• The Air Force picked up the Discoverer flight-test program in June. Discoverer XXIV failed to orbit because of a second-stage ignition failure, but Discoverer XXV attained orbit a week later and successfully returned its data after two days in orbit. The C-119 squadron failed to retrieve the capsule in the air, but it was recovered by three AF sergeants who parachuted to the floating capsule and placed it aboard a large life raft to prevent it from sinking. (Discoverer capsules are provided with water-soluble plugs so that they will flood after 40 hr if they are not picked up from the ocean. This procedure is aimed at preventing "unauthorized persons" from recovering them.)

• NASA awarded Douglas Aircraft a $450,000 contract to study the development of orbital-placement techniques for the Rebound passive communication satellite. Two Atlas Agena-B launchings are planned in 1963 with three of the 135-ft Rebound spheres planned for each vehicle. Douglas will devise a means of injecting the satellites into a common circular orbit at 1500–2000 mi. altitude with equal circumferential spacing among the satellites.

• Martin is vigorously pushing the Titan II vehicle as a space booster for future NASA programs. Its engineers say the 430,000-lb-thrust Titan II can orbit 9000 lb. With the Centaur as a third stage, it could manage 13,000 lb, and 15,000 lb with a new fluorine–hydrogen third stage. Martin is hopeful that the AF will specify the latter stage in the program to develop a Centaur back-up vehicle based on Titan II, since this would give the vehicle a payload capability rivaling that of Saturn C-1.

• NASA was expected to sign a contract shortly with American Telephone & Telegraph Co. to orbit a prototype 130-lb communication satellite. This active repeater would be placed in an orbit with a 5000-mi. apogee about mid-1962. Its development and testing would be integrated into NASA's over-all program to develop active relay satellites, indicating that AT&T will have considerably less latitude in the operation than it had originally sought. NASA will retain over-all control of the nature of the satellite, its experiments, time of launching, and coordination with other government programs, notably Project Relay, under development by RCA.

• In another action which seemed to favor a widening of the ownership of the proposed active relay satellite system, President Kennedy directed the National Space Council to study the communication satellite problem and make recommendations on the type of system the U.S. should develop. The White House interest in the problem suggested that the views of the Justice Dept. might have more weight in its solution than those of the Federal Communications Commission. FCC has favored a program restricting ownership to international-communica-



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tion common carriers; Justice Dept. has been pushing for inclusion of equipment manufacturers, such as General Electric and Lockheed.

PROPULSION

• The initial flight tests of the Rover engine will probably be conducted on a ballistic trajectory over the Atlantic Missile Range. The Rover would be carried into space by a C-1 Saturn stage before reactor activation. Companies hired by NASA to study the Rover flight-test problem concluded that orbital testing was possible, but that weight limitations would sharply restrict the amount of propellant which could be carried, and consequently limit too drastically the operating time of the reactor.

• NASA scheduled March 1965 as the target date for a flight test of the Snap-8 nuclear reactor, which will produce 30-kw of electrical power. The Snap-8 reactor will be orbited by an Atlas-Centaur along with three electrical rockets—a 30-kw arcjet to be developed by either GE or Avco, a 30-kw ion motor by Hughes or NASA-Lewis, and a 1-kw arcjet under development by Plasmadyne Corp. The Plasmadyne engine would control attitude of the vehicle. The 30-kw arcjet would run first, until its propellant supply exhausted, and then the ion motor would operate for the remainder of the reactor's life. Scientific payloads might be carried in the flight, but the vehicle would probably be held in the vicinity of the earth to facilitate transmission of flight-test data.

• NASA narrowed to four—Douglas, Aerojet-General, General Dynamics, and North American—the number of companies eligible to submit proposals for development and production of the Saturn S-II. The companies were scheduled to submit final proposals on the S-II last month, so that NASA could complete its evaluation and award a final contract by Oct. 1 of this year. The S-II, largest rocket so far undertaken by U.S. industry, will be powered by four J-2 engines developing a total thrust of 800,000 lb.

• NASA solved its embarrassing Saturn transportation problem, but the solution proved a little embarrassing, too. When a lock collapsed at Wheeler Dam on the Tennessee River this spring, it trapped upstream at Huntsville the special Saturn barge *Palaemon*, built at a cost of $360,000 to haul the 82-ft S-I stage to Cape Canaveral. The Navy came to the rescue. It located a World War II covered lighter moldering away at Jacksonville, Fla., that could be pressed into service with minor modification costing $43,500. It seemed too bad the Navy did not come forth with this beauty when plans for the *Palaemon* were announced.

• The present plan is to haul Saturn from Huntsville to the dam aboard *Palaemon*, haul it by road to a point below the dam, and there load it on the Navy lighter, which will carry it the remainder of the 2100-mi. journey to Florida.

• Boeing will explore the development of solid rockets of the Saturn and Nova class—consisting of large single or clustered motors, segmented or unitary, in combination with one or more high-energy liquid-propellant upper stages—for NASA-Marshall Space Flight Center under a six-month contract for $100,000. Drawing on data generated by three recently completed solid superbooster studies conducted for NASA by Aerojet-General, Grand Central Rocket, and Thiokol Chemical, Boeing will emphasize systems engineering and logistics of space transportation under realistic conditions. The study covers total orbital transportation costs, operational advantages and constraints, and recovery of spent stages. For an insight into the growing solid-rocket story, see William Cohen's article on page 22.

• United Technology Corp. successfully static-fired a company-developed solid rocket containing about 1000 lb of propellant. The company claims unusual potential for this motor as a high-performance upper stage. Recently, UTC received contracts totalling about $230,000 from the AF Flight Test Center, Edwards AFB, and ONR for development of high-performance solids and for research on the thermochemistry of the high-energy fluorin bond, respectively . . . Thiokol-Elkton and Atlantic Research also received contracts of $492,000 and $346,000, respectively, from the Flight Test Center for development of high-energy solid propellants.

• Rocket Power, Inc., announced a new solid motor, the Kisha. This 6.5-in.-diam, 72.1-in.-long motor weighs 145 lb loaded and 42 lb burnt, produces a nominal 4800-lb thrust for 4.8 sec, and uses a hot-particle "shockless" igniter. Burning time and thrust can be tailored to application. Rocket Power also received a $68,000 contract from Sandia Corp. for its Gila III solid-propellant sled motor, which produces 21,300-lb thrust for 3.1 sec., and saw its Phoenix sounding rocket launched from NASA's Wallops Island facility for the first time in a program conducted by the Leesona Corp.'s Patterson Moos Research Div. for the AF (ASD). The 325-lb Phoenix, which can boost a 10-lb payload to an altitude of 250-mi., has now been launched successfully 17 times in a row.

• Aerolab Development, subsidiary of Marshall Industries, will prepare an Aerolab Argo D-8 four-stage solid rocket for launching the Nerva II nuclear-emulsion research package into space late in 1961 under a NASA-Goddard contract. . . Allied Chemical's Nitrogen Div. announced plans to double its capacity for nitrogen tetroxide by building a new plant at its Hopewell, Va., facilities. The move reflects the growing use of N_2O_4 in missile and space-vehicle upper stages. . . Clauser Technology Corp. of Los Angeles will study the feasibility of the magnetic-induction plasma engine for space vehicles under a NASA contract for some $100,000. People will be watching the potentially versatile and efficient magnetic-induction engine carefully.

• The main spring in NASA's advanced-Saturn and Nova studies, the Rocketdyne 1.5-megalb-thrust F-1 engine, has entered a series of static firings as a complete, self-cooled unit at Edwards Rocket Test Center.

SPACE TECHNOLOGY

• The USAF Arnold Engineering Development Center at Tullahoma, Tenn., has commenced development of an $11 million vertical cell for simulated high-altitude testing of rocket engines ranging up to 500,000-lb thrust. Measuring 100 ft in diam, the cell requires an excavation 250 ft deep and will extend 100 ft above the ground. It is to be ready for operation by early 1963.

• NASA's Jet Propulsion Laboratory is building a $4 million space environment chamber for testing the Mariner A and subsequent spacecraft. To be completed by the end of this year, the chamber will simulate the vacuum and solar radiation of space. Principal features of the facility are a complicated lighting system to produce intense heat and a 28,000-gal liquid-nitrogen system to carry

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heat away from the walls of the chamber. The lighting system utilizes 150 mercury-xenon arc lamps and an intricate series of mirrors and lenses to generate artificial sunlight within the chamber.

• NASA's $13-million Plum Brook Reactor has gone "critical" at the Lewis Research Center facility near Sandusky, Ohio. The reactor is to be brought up to 100 kw over a period of several months, shut down and inspected, and then increased to a rating of 60,000 kw. The chamber will be used to test radiation effects on pumps, turbines, propellant feed systems, shielding and other materials at both cryogenic and very high temperatures.

• The AF earmarked the largest share—$602 million—of its Fiscal Year 1962 research funds for space projects. Missiles placed second at $300 million and aircraft (including Dynasoar) third at $239 million. Major USAF space items for Fiscal 1962 (with Fiscal 1961 amounts in parentheses) include Samos observation satellite—$276 million ($273 million); Midas early-warning satellite—$201 million ($107.4 million); Discoverer experimental satellite—$54.9 million ($55.1 million); Project Saint for satellite inspection—$26 million ($6.1 million); and Space Detection and Tracking System (Spadats)—$30 million ($3.3 million).

WEAPONS

• Terminal defense against a broad and deep attack of decoy-accompanied ballistic missiles will be studied by the Raytheon Co. and associates Hughes, Boeing, IBM, and Bissett-Berman Co. under a $7 million contract issued by ARPA as part of its Defender program. This "Arpat" system involves the launch of anti-missile-loaded vehicles into a defense zone. A vehicle would be slowed and stabilized at some altitude up to 20 mi., and then its warheads, sets of radiation-homing missiles, would be ripple- or salvo-launched, depending on the developing history of the attack. This is but one of a series of ARPA studies of ballistic-missile defense under the Defender program. ARGMA will manage the Arpat study.

• Testifying to Congress recently, the AF reported that midcourse and terminal decoys are being developed that cannot be distinguished from ballistic-missile warheads. "New re-entry vehicles (ICBM nose cones) of low radar cross section and advanced decoys which will completely simulate the re-entry vehicle and incorporate other devices for confusion are planned," Congress was told. The inference was that the Russians can do the same thing and that Nike-Zeus looks even less promising now as an effective counterweapon to a ballistic-missile attack.

• The Pershing two-stage solid-propellant ballistic missile is moving toward a full field evaluation this fall. The Army awarded Martin-Baltimore contracts totalling $7.8 million for additional hardware and development, some $3 million of which is for training equipment, to be supplied by Martin-Orlando. ABMA supervises the development . . . The Mauler missile system for field defense of fast-moving columns against aircraft and missiles received further support with a $6.22-million Army contract to Convair-Pomona . . . The AF awarded Martin-Baltimore a $2.25-million contract for initial production of the GAM-83B nuclear warhead for the radio-controlled Bullpup air-to-ground missile . . . Rocketdyne's Solid Propulsion Operations, McGregor, Tex., will develop a new solid motor for the Sparrow air-to-air missile under a $675,000 Bureau of Weapons contract.

• The Navy picked Bendix Corp. to develop the long-range Typhon missile (formerly Super Talos). Rocket boosted and ramjet sustained, Typhon provides fleet defense against aircraft with stand-off missiles as well as surface-to-surface offensive capability against enemy fleet units. Prime contractor for the system, Westinghouse Electric, has been working for more than a year on shipboard electronics, including radar and fire control.

• After a harrowing flight-test program, Convair and the AF finally seemed to be beating the bugs from Atlas-E last month. On the heels of two explosive failures in June, Convair successfully launched an Atlas-E on a 9050-mi. flight from Cape Canaveral to the Indian Ocean. An Arma inertial system guided the test missile. Tracking planes and a ship witnessed the 3000-lb nose cone re-enter the atmosphere.

• The 9050-mi. flight gave Atlas-E a record of four complete successes, five partials, and two failures since Oct. 1960, by AF reckoning. Although no pattern has been disclosed, the failures tended to occur in the souped-up 387,000-lb-thrust MA-3 powerplant provided for the ICBM, according to the AF. Success for Atlas-E can come none too soon, as early last month a committee headed by Clark Millikan of CalTech began a review of the Atlas-E program.

R&D

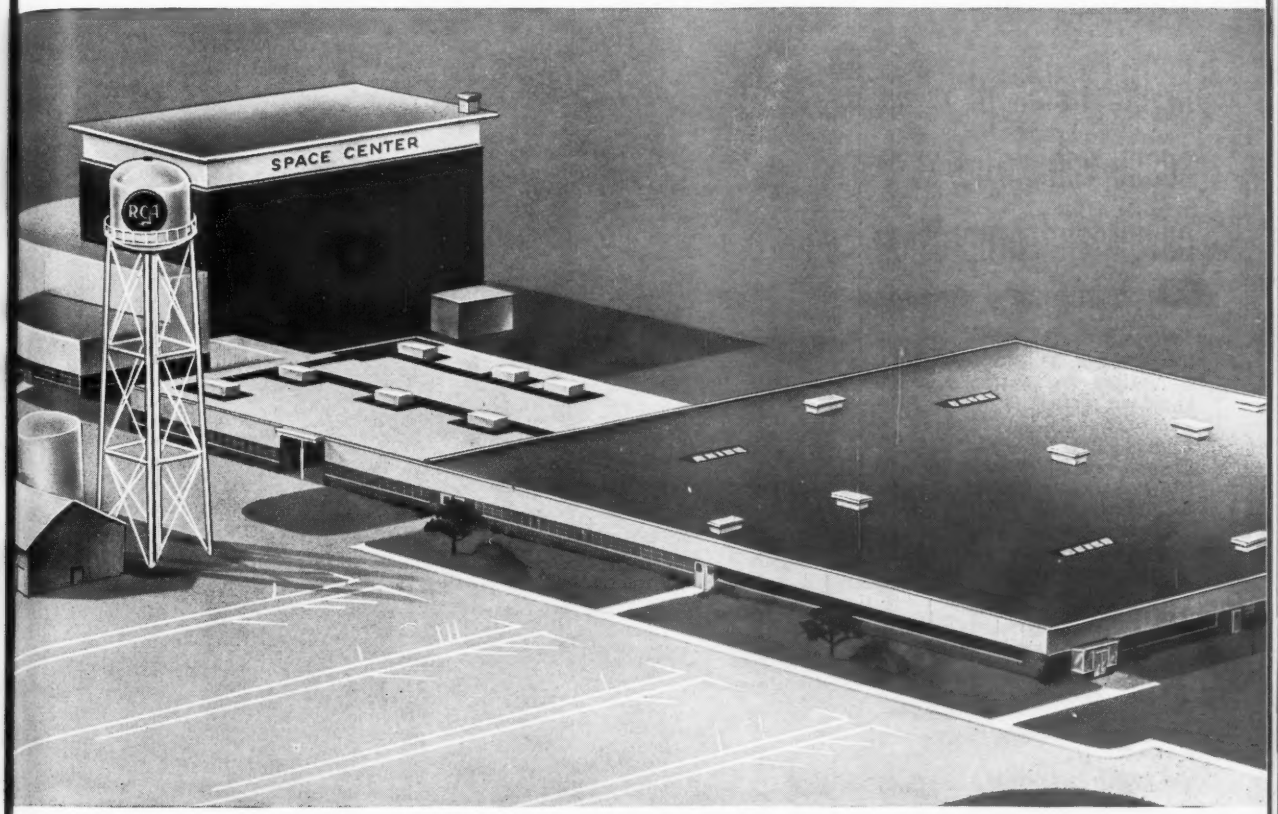
• Although the AF is holding off any systems design based chiefly on molecular electronics, it continues to encourage the development of molecular-electronic components, and has contracted with Motorola's Semiconductor Products Div. to the tune of some $1.5 million for the development of compatible techniques for fabricating complete circuit functions by combined semiconductor processes and thin-film technology. According to Motorola, after exploring reproducibility, reliability, and performance range, it will identify techniques most suitable for integrated circuits, and will combine specific electronic functions into integrated-circuit function models. The contract calls for Motorola to contribute to the cost of the whole program.

• Along this line, Westinghouse Electric announced that its Air Arm Div. is developing a molecular-electronic computer (Mol-E-Com), which will weigh less than 15 lb and occupy less than $^1/_3$ cu ft (corresponding transistorized one weighs 175 lb and occupies 3 cu ft), and will form a new department for the development, manufacture, and marketing of molecular-electronic functional blocks.

• Burroughs Corp. has just delivered to the Navy a transistorized airborn digital computer for fire control and navigation that weighs less than 190 lb and occupies only 3 cu ft. Designed under the direction of the Naval Ordnance Test Station (NOTS), the computer contains a magnetic-drum memory capable of storing 215,000 bits. A linear-select, random-access ferrite-core memory of 11,500 bits stores initial conditions and transient data. Burroughs sees the computer as a candidate for the central computer of manned space vehicles and as a prelaunch computer for air-to-ground missiles.

• GD-General Atomic will explore the possibility of extracting alternating current at radar frequencies from a cesium-cell thermionic converter under a $60,000 AF Rome ADC contract. ♦♦

New RCA Space Environment Facility Brings Outer Space Down to Earth...



... Will pretest coming generations of U.S. space vehicles and satellites at environmental extremes assuring reliable long life operation and optimum performance.

Included in the new environmental equipment and facilities being built and installed at the RCA Astro-Electronics Division at Princeton, N.J., are the following advanced testing devices:

Vacuum-Thermal Chamber — measuring 28 feet in diameter and 25 feet high to accommodate the coming generations of space vehicles and satellites and meet all vacuum-thermal requirements.

Vibration System — provides 28,000 pounds peak force for sinusoidal, and 28,000-pound rms force for random motion testing.

Temperature-Humidity Chamber — so versatile it can create virtually any thermal-humidity condition desired. Temperatures may be varied from —85° F to 250° F: humidity from nil to maximum.

Rotary Accelerator — subjects subsystems of space vehicles and satellites to forces as high as 2500 g lbs.

The entire RCA Space Center, which contributed to the success of projects such as SCORE, TIROS I, TIROS II and ECHO I, continues to be dedicated to the conception, development and production of earth satellites, space vehicles and ground support and information handling equipment. For additional information about RCA's engineering talents and proved capabilities, contact the Manager, Marketing, RCA Space Center, Box 800, Princeton, N. J. And, for a complete description of the new environmental facilities, write for your copy of the brochure "RCA Space Environment Center."

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ENGINEERS & SCIENTISTS in the fields of space vehicle power and propulsion

The Propulsion and Power Systems Department of the Aerospace Vehicles Laboratory has several unusually interesting openings for engineers and scientists who are interested in the fields of space vehicle power and propulsion. The openings are at all levels of experience – from recent graduates to the senior staff level. Most of the positions will involve design and analysis of power and propulsion systems for satellite and space probe application. Specifically, some of the areas of specialization are:

1 SPACE POWER SYSTEMS
The positions will involve analysis and development of such energy sources as: photo voltaic, thermionic, thermoelectric, battery and advanced energy storage systems.

2 SPACE PROPULSION SYSTEMS
The positions will involve the preliminary and conceptual design and comparative analysis of all types of chemical and electric propulsion systems.

3 PROGRAM MANAGEMENT
The positions will be associated with the development of solid and liquid propellent rocket engines. Advanced degrees are preferred and considerable experience in the field will be required.

If you are interested and believe that you can contribute, please mail your resume to:

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For the record

The month's news in review

June 1—Russians disclose launching and landing sites of Vostok, which carried Maj. Yuri Gagarin, were Baikonur and Smelovka, respectively.

June 3—Aerojet-General solid rocket generates 500,000-lb thrust during static firing.

June 5—Eleven-million-dollar Saturn facility at Cape Canaveral is dedicated.

—DOD tells AF to let research contracts for Bambi (Ballistic Missiles Boost Intercept) system.

June 6—AF Aerobee-Hi Venus flytrap fired to 102-mi. altitude above White Sands, N.M., encounters a band of micrometeorites 100 times as dense as anticipated.

June 8—Discoverer XXIV fails to orbit.

—Portable Army rocket propels a man to 15-ft altitude and 150-ft distance in 14-sec test.

June 15—British and Russian scientists end search for Russian Venus rocket launched Feb. 12.

—President Kennedy orders study by Federal Space Council on operation and ownership of communications satellite system, and how program can be accelerated.

June 16—Discoverer XXV is shot into polar orbit.

June 19—Three X-15 pilots—Scott Crossfield, Joseph Walker, and Maj. Robert White—are named joint winners of 1961 Harmon Trophy.

June 21—AF Mace-B ends R&D phase with successful 1100-mi. guided flight test.

June 22—Polish astronomer, K. Kordylewski, of Cracow Observatory, reports having photographed two cloud-like objects which could be natural satellites of the earth.

June 23—Maj. Robert White guides X-15 to speed of 3603 mph.

June 24—NASA modifies Mercury capsule for second space flight—large observation window replaces the two viewports and more advanced manual control system is added.

June 27—Senate approves $1,784,300,000 NASA budget for fiscal 1962, including $549 million increase proposed by the President.

June 29—Navy launches three-in-one satellite—Transit IV-A, Injun, and Greb—into orbit, but only Transit, carrying atomic battery, separates from other two satellites.

June 30—Scout satellite orbital shot fails when third stage doesn't ignite. ♦♦

He's solving a real estate problem

This AMF engineer's job is determining how best to move big missiles off shore for launching. Should they be floated out horizontally, flooded to an upright position, and then launched? Or, would it be more feasible to barge them out? Might they be moved to or assembled on "Texas Towers," or would a causeway or simply land-fill be the answer?

Behind the project is our shrinking real estate at launching sites, plus the hazards inherent in launching Saturn-sized missiles (and the coming, nuclear-powered missiles) near other installations. Off-shore launching may be the answer.

Feasibility studies of all types are an AMF specialty. What kind of remotely controlled machinery is required to service nuclear-powered aircraft? What kind of habitation could be built on (or under) the surface of the moon? What sort of machines (manned and unmanned) could survey the moon's surface without, for example, falling into a fissure? What is the best way to assemble a space station? All these are problems AMF engineers are presently investigating.

If your problem is the first of its kind, AMF will not, of course, have met it before. But AMF's long experience in accepting totally unique challenges gives it an advantage enjoyed by few other organizations concerned with ground support, launchability and space environment. To get further information write American Machine & Foundry Company, 261 Madison Avenue, New York 16, N. Y.

AMF

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People in the news

APPOINTMENTS

Maj. Gen. William L. Rogers has been named commander of the AF Arnold Engineering Development Center. Gen. Rogers, former vice-commander of the AF Missile Test Center, Patrick AFB, succeeds **Brig. Gen. Homer A. Boushey,** who is retiring from the Air Force. **Col. Harry J. Sands Jr.** succeeds Gen. Rogers as AFMTC vice-commander.

Brig. Gen. Francis J. McMorrow has been appointed deputy commanding general of the Army Ordnance Missile Command. Gen. McMorrow, who has been nominated for promotion to major general, succeeds **Maj. Gen. John A. Barclay,** who has retired from active duty with the Army.

D. D. Wyatt, former assistant director in NASA's Office of Space Flight Programs, has been named director of the Office of Programs in the Office of the Associate Administrator.

James R. Dempsey, an ARS director, has been appointed president of General Dynamics/Astronautics and a senior vice-president of General Dynamics. He formerly was a vice-president of the Convair Div. and manager of its Astronautics operating division. Also at GD/A, **Mortimer Rosenbaum,** formerly chief engineer, becomes executive vice-president; **Wallace W. Withee,** formerly senior assistant chief engineer, becomes vice-president of research and engineering; and **Elwood D. Bryant,** formerly operations manager, becomes vice-president of operations.

William H. Dorrance, chairman of the ARS Hypersonic Technical Committee, has been appointed head of the Aero-Analysis Dept. within the Spacecraft Sciences Sub-Division of Aerospace Corp. He was formerly assistant to the director of scientific research at Convair-Astronautics.

Maxwell W. Hunter, former chairman of the ARS Missiles and Space Vehicles Technical Committee, has been promoted from assistant chief engineer to deputy chief engineer-space at Douglas Aircraft. **A. J. Carah** has been upped to assistant chief engineer-missiles. Members of the newly established Douglas Scientific Directorate are **Mervin J. Kelly,** former president of Bell Telephone Laboratories; **Charles C. Lauritsen,** professor of physics, California Institute of Technology; **Roger R. D. Revelle,** director of Scripps Institute of Oceanography and dean of the Univ. of California; **Otto H. Schmitt,** professor of physics and zoology, Univ. of Minnesota; and **William R. Sears,** director of the Graduate School of Aeronautical Engineering at Cornell Univ.

Lovell Lawrence Jr. has been appointed director of the Advanced Projects Organization, Defense Group, at Chrysler Corp., where he formerly was executive engineer, APO. **William S. Blakeslee,** general manager, Defense Operations, has been promoted to group executive, defense, succeeding **I. J. Minett,** who has been upped to group executive and chief operating officer of the International group.

Charles W. Williams, former president of the ARS Detroit Section, has been appointed director of research, Bower Roller Bearing Div. of Federal-Mogul-Bower Bearings, Inc. He formerly was director of manufacturing operations at Chrysler Corp.'s Advanced Projects Organization.

Harvey M. Cook, president of the ARS Tennessee Section, has been named assistant to the director of engineering, ARO, Inc., at Tullahoma, Tenn. He was formerly manager of operations, Rocket Test Facility.

Donald H. Loughridge, formerly head of the Physical Research Dept., General Motors Research Laboratories, has been named director of applied research management, Aerospace Corp. **Matthew H. Portz** becomes manager of public information.

Stanley F. Sarner has transferred from GE's Flight Propulsion Laboratory to Thiokol's Elkton Div., where he is working in Theoretical Analysis.

John I. Mika has been named director of ordnance engineering, Ordnance Operation, Avco's Electronics and Ordance Div.

HONORS

Mrs. Esther Christine Goddard, widow of rocket pioneer Robert H. Goddard, recently was presented with the Robert H. Goddard Medal, authorized by the 86th Congress, in honor of her husband's life work. Mrs. Goddard was also the recipient of an honorary degree of Doctor of Science from Nasson College, Springvale, Me.

Laurel van der Wal, head of bioastronautics at Space Technology Laboratories, Inc., has been awarded the 1961 Society of Women Engineers Achievement Award.

Eberhardt Rechtin, consulting editor of *Astronautics,* and chief of JPL's Telecommunications Div., has been named Telemetry Man of the Year at the National Telemetering Conference. The award is given to the person who has contributed most to the science of telemetry during the year.

Eino K. Latvala, chief of ARO, Inc., Aerospace Research Group at Arnold Engineering Development Center, has been named to receive the first ARO von Karman grant, which assists in providing faculty members to the Training Center for Experimental Aerodynamics near Brussels, Belgium.

Vice-Admiral William F. Raborn Jr., director of Special Projects for the Navy, has been awarded the Robert J. Collier Trophy for directing the creation of the Polaris missile weapon system. ♦♦

Rogers

Boushey

Dempsey

Dorrance

Lawrence

Williams

Reaction controls at work in space — symbolized.

STEERING GEAR FOR MERCURY ASTRONAUTS

Conventional aircraft control surfaces will not guide space ships and capsules. Rudders, ailerons and elevators find no resistance and hence produce no reaction to their movements where there is no atmosphere. Even at altitudes only half way up, they are sluggishly ineffective.

The accepted answer to a dependable steering mechanism for astronauts is a system of jet reaction controls developed and produced by Bell Aerosystems Company. First used on Bell's own supersonic X-1B several years ago, the system has been greatly improved and adopted for the X-15, the Mercury man-in-space project and other space vehicles.

Through strategically located, low and high thrust (1 to 1500 pound) rocket engines, Bell's reaction controls not only position and guide the ship by controlling the roll, pitch and yaw, but they also provide for orbit changes and retro-thrust. Some of the jets are throttleable while others can be operated in combination to provide the astronaut positive and flexible control.

This revolutionary steering gear for space, available using monopropellants or high energy bipropellants, is just one of many advanced projects which are currently engaging the diversified talents of Bell Aerosystems Company in the fields of rocketry, avionics and space techniques. Engineers and scientists seeking challenging, long-range career opportunities can find them at Bell.

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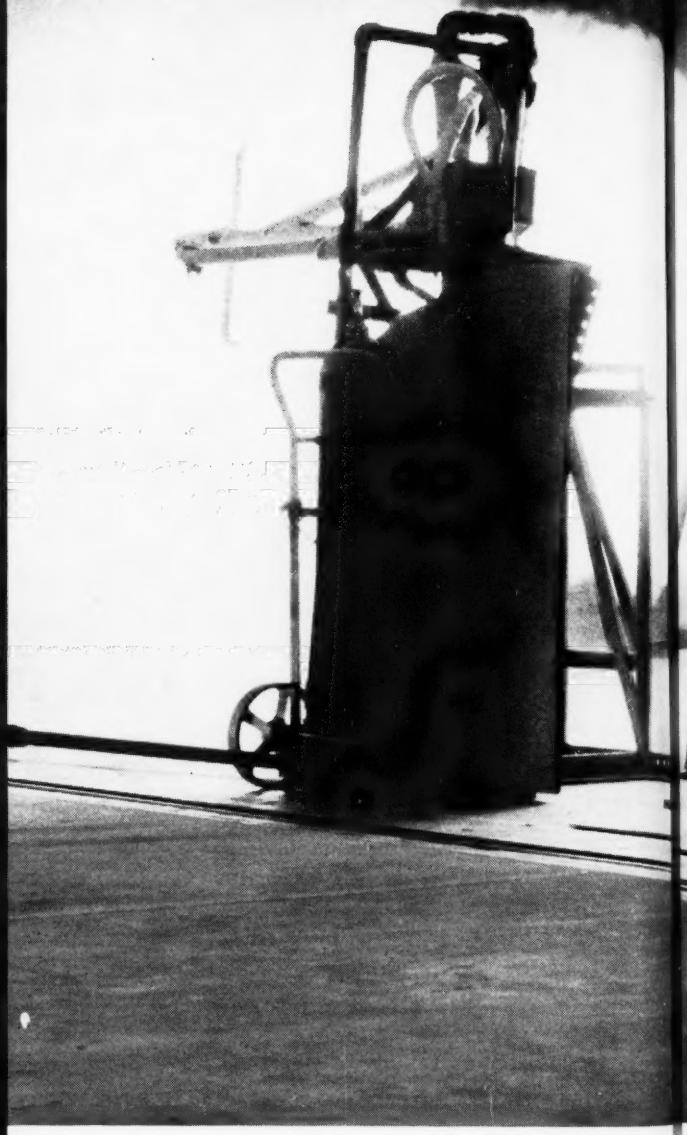
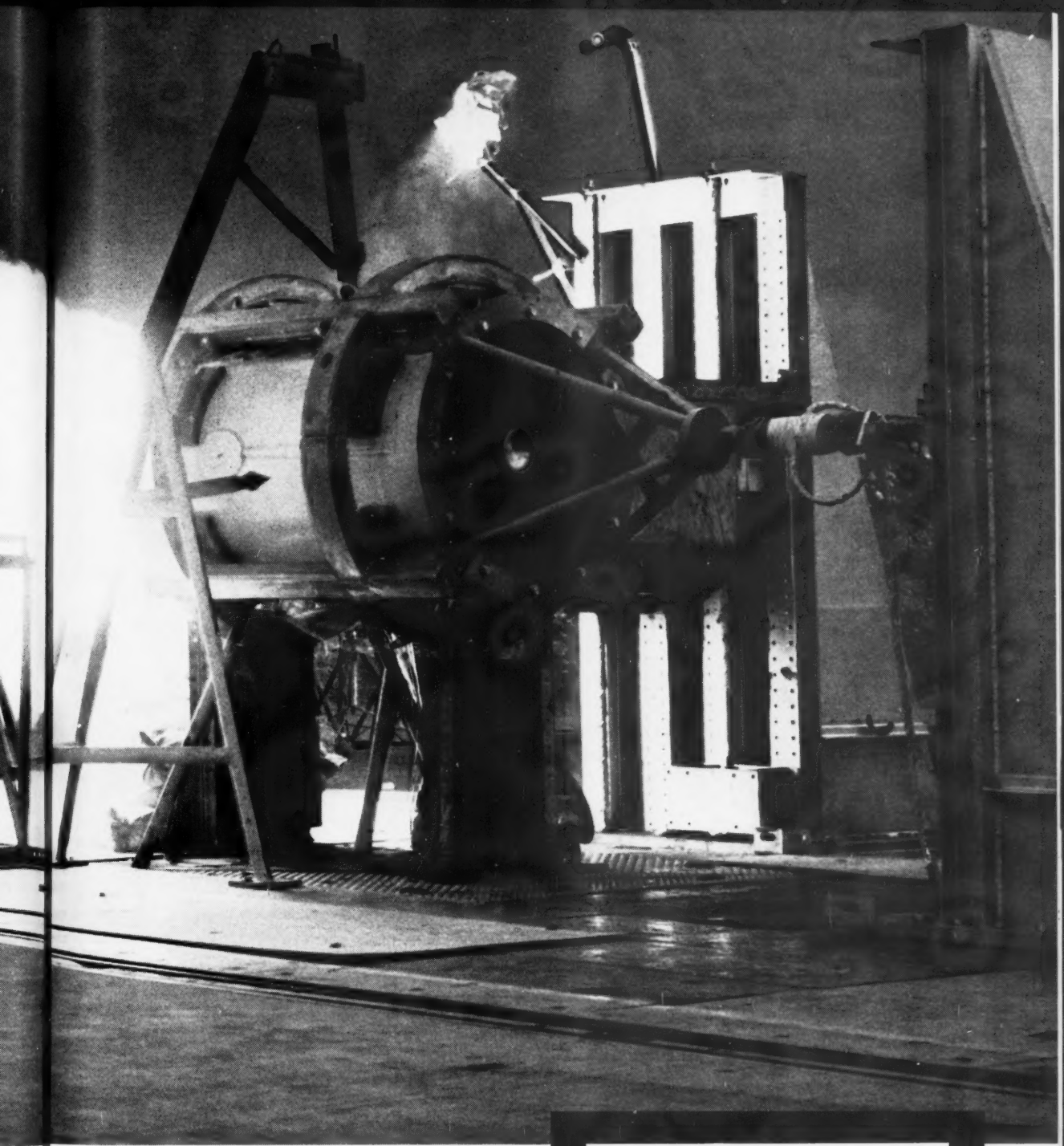
HERE'S HOW WE MEASURE MISSILE MUSCLE



This is one of the test-bays at the Hercules-owned-and-operated plant at Bacchus, Utah. Here the third-stage engine for the Minuteman rocket was developed and is manufactured for the Air Force. The advanced second-stage Polaris engine, developed for the Navy at Allegany Ballistics Laboratory, is also being manufactured here. Hercules' Bacchus plant is a fully integrated facility for research, development, and production line manufacture of high-specific-impulse solid-fueled rocket engines.

As each new design-idea is proved out in roaring flame, a net of cunningly placed transducers take the engine's pulse, its temperatures, check its pressures, stresses and thrusts. This welter of information is fed, at 20,000 bits



per second over 240 separate input channels, to a central data acquisition room where it is permanently recorded on synchronized magnetic tapes. Meanwhile, as many as twelve high-speed cameras exposing up to 3,000 frames a second on a quarter-mile of film, keep a visual record of everything that happens with thousandths-of-a-second accuracy.

Thus, each test of component, propulsion unit, experimental design or completed engine yields a maximum amount of information ready for computer analysis and integration to advance both design criteria and manufacturing methodology. This is just another example of Hercules imagination in propulsion engineering.

Chemical Propulsion Division

HERCULES POWDER COMPANY
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Hercules Tower, 910 Market Street
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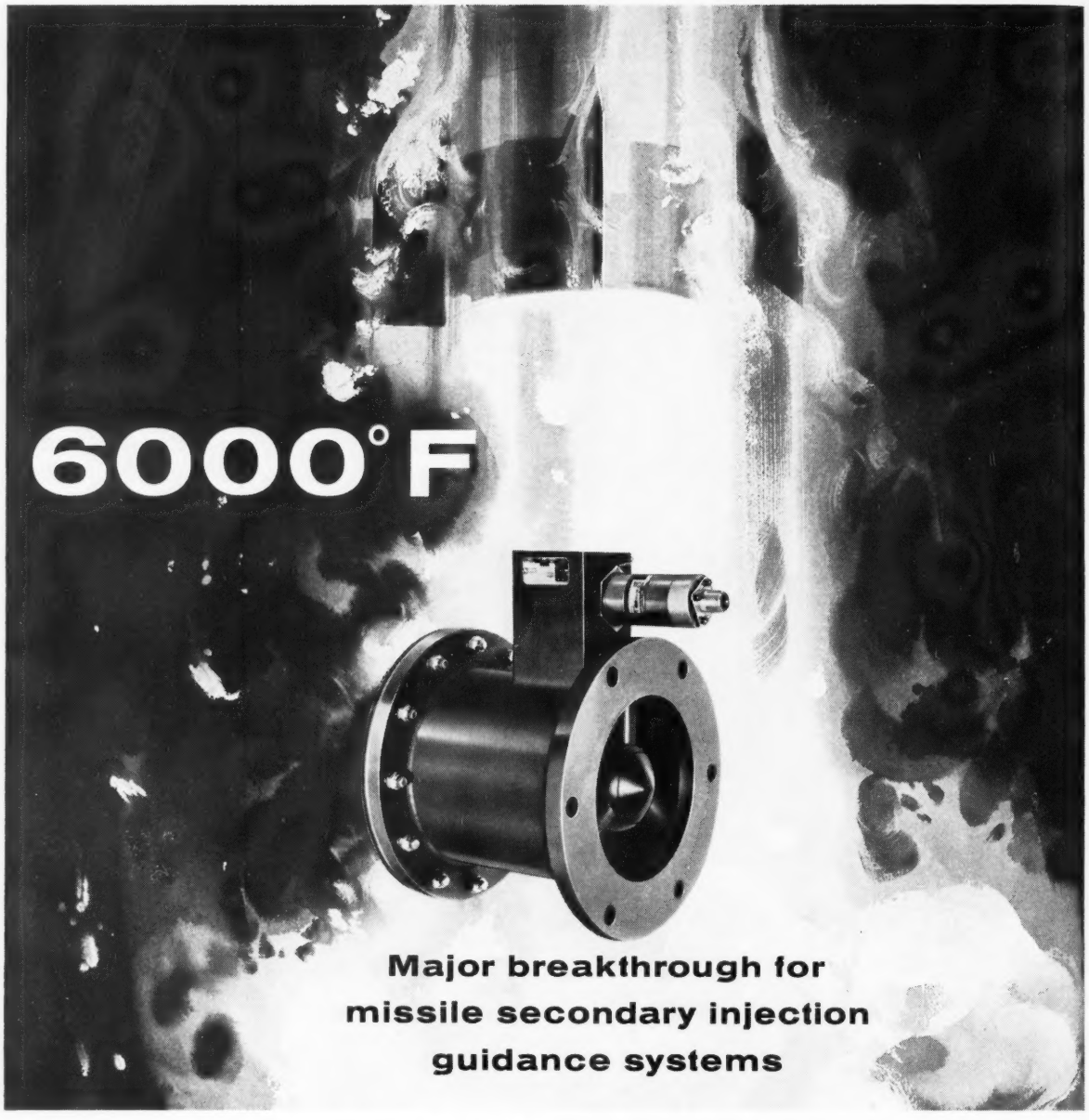

This AiResearch ultra-high temperature shutoff valve has been tested at 6000°F. Its development makes possible the use of secondary injection thrust vector control for greater simplicity and reliability.

This high temperature capability is an extension of previous AiResearch valve and controls experience in the —423 to 2000°F range, and further demonstrates over-all capability in the design of complete missile and ground support systems.

An inline poppet valve of extremely clean design has been produced to handle the high speed flow of hot, contaminated gas ducted from the combustion chamber to the exhaust nozzle. This design will: (1) keep lodging of contaminants to a minimum; (2) reduce turbulence and uneven wear; and (3) permit only a small pressure drop across the valve at maximum flow.

Growth into high temperature ranges can be accomplished by changes in material without changes in the basic valve design. The extreme compactness and light weight of the valve make it ideally suited for installation in the isentropic spike of a plug nozzle.

• *Please direct inquiries to Control Systems Project, Phoenix Division*

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Meeting the Cost of OUR Obligations

In a few weeks, we of the American Rocket Society will be asked to participate in a momentous decision for the Society. In preparation for that decision, I hope every member will read this editorial.

This spring, the President of the United States declared that it is time for our nation to take a clearly leading role in space achievement and, more particularly, to place a man on the moon within this decade. Helping the professional rocket and space-flight community to live up to the role the President and the nation have assigned it is one of the primary functions of the ARS; for there can be no adequate technical progress in so vast and complex a field except through fast, adequate, and accurate technical communications, such as are afforded by ARS publications and meetings.

These communciations cost much money, and the job is getting bigger and more costly every day. To publish its magazines, hold its meetings, and otherwise serve those who depend on it, ARS now spends about $60 per member each year. Money to make this possible comes from dues, advertising, exhibits, corporate members, and government grants. Dues represent by far the smaller part of our income. A member pays only $15 yearly toward the cost of the services he receives; a student member pays only $5.

ARS now provides more services, for the same or lesser dues, than most other technical societies. Few other major societies, for example, give professional members *two* monthly journals at no cost beyond the regular dues. It has been the judgment of the ARS Publications Committee, and I believe a sound one, that the broad dissemination of the information contained in both *Astronautics* and *ARS Journal* is essential to the vigorous health of the rocket and astronautics field, and the two-journal policy will be continued.

But the task of communications is an ever-growing one. It continues to increase in spite of the maintenance of rigorous publication standards. In 1954, members received for their $15 dues 420 pages of technical information in six bi-monthly issues of a single journal. In 1960, for the same small sum, they received 2514 pages in 24 issues of two journals. This year the volume will be even greater. In 1962 it will increase again.

Through grants-in-aid from the National Science Foundation, it has been possible so far not only to keep members informed of our own technical progress, but also in the last two years further to increase the value of the *ARS Journal* by adding a bi-monthly Russian Supplement and to double the volume of the regular content. However, as part of the terms of the NSF grant, the Society is committed by the end of next year to take over the *total costs* of the expanded *Journal*. Any further expansion of ARS journals required to publish the growing volume of important technical material must also, of course, be financed by the Society.

Accordingly, on June 15th at Los Angeles, the Board voted 15–0 in favor of raising the dues $5 for all members of the Society except Student Members, beginning January 1, 1962. Even with this increase, our dues will be no greater, and in several instances will still be less than those of other major technical societies.

In a few weeks, members will be asked to ratify this Board action by mail ballot. *I urge every member to vote affirmatively.*

The dues increase is an important investment for us in the future of rocketry and astronautics.

Harold W. Ritchey
President, AMERICAN ROCKET SOCIETY

Solid rockets for space vehicles

Thoroughgoing analytical programs and limited experimentation to date have indicated the feasibility of the large solid booster, but problems centering on long burning times, man-rating the motor, reliability, ignition, and vehicle dynamics must be solved before it becomes a reality

By William Cohen

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, WASHINGTON, D.C.

William Cohen is chief of Solid Propulsion Systems at NASA Headquarters. Prior to joining NASA in September 1960, he was employed in the Special Projects Office of the Navy Dept., where he was the Propulsion Section Chief Civilian Engineer, engaged in the development of the Polaris propulsion system. He came to the Polaris Program in 1956 from the Naval Ordnance Test Station, where he was most recently head of the Process Development Branch. He has been working on liquid- and solid-propellant rockets since 1948, specializing in thermodynamics of combustion, propellant processing, and ballistic-missile design.

As I was fidgeting in my chair, trying to think of a good opening sentence for this paper, I glanced out of my office window to the new building across the street. It is 10 stories high. A quick mental calculation showed that my solid-rocket motors will be just around the same height. Some further rough calculations told me that the weight of this new building was about 8.75 million lb, a little lighter than the solid-propellant stage I will describe later in the paper.

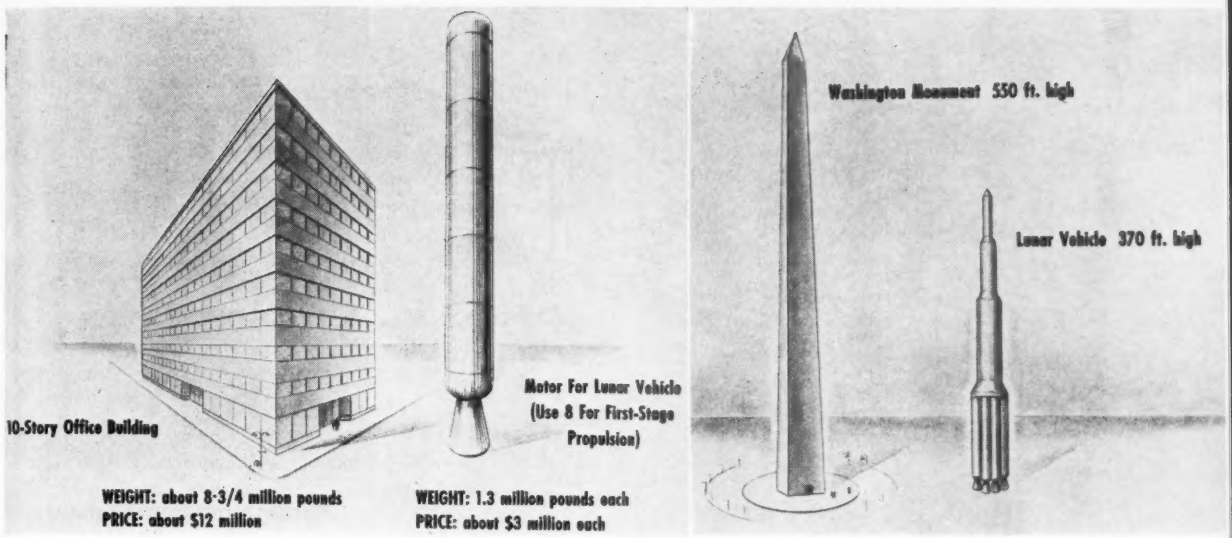
By now caught up in the comparison, I did some checking, and discovered that I can buy the 10-story building for about $12 million. The rocket motors I discuss here are individually cheaper, retailing at about $3 million each, but I'll need eight of them for the first stage of the lunar vehicle. I'll have to put out $24 million, for which I could obviously buy the building across the street and a spare building to boot.

My costs for propulsion, however, do not end with purchase of the motors, since I will spend another tidy sum to bind these into a stage and provide the other pieces of equipment to make the stage function properly. I continued this rather distressing comparison by considering that the office building has a useful life expectancy of at least 20 yr, whereas my rocket motors will be gainfully employed for no more than 2 min.

After putting my feet on the desk for a while, I consoled myself with the thought that the solid propulsion stage for a lunar vehicle probably represents no more than one-fifth of the total vehicle cost—a rather Pyrrhic consolation.

My reason for opening the paper with this rather gloomy comparison is to establish the proper frame of reference. Space exploration is a fabulously expensive, massive, and difficult operation. I'll skirt the question of why we want to explore space and go on to the specific question of why we want to use solid-propellant elements in space-exploration vehicles. Some competitors of the solid-rocket industry maintain that the solid industry suffers from the Everest Syndrome: "We must develop solid rockets for space because *it is there* and we must conquer it." The solid industry can be equally snide, stating that their liquid-propellant competitors have long suffered from the Horse Syndrome: "We have always used the horse to carry things from point A to point B. He is occasionally a cantankerous beast, and has a few annoying flaws, but we know them well by now.

Large Solid Boosters: How Big and How Much?


10-Story Office Building
WEIGHT: about 8-3/4 million pounds
PRICE: about $12 million
Motor For Lunar Vehicle
(Use 8 For First-Stage
Propulsion)
WEIGHT: 1.3 million pounds each
PRICE: about $3 million each
Washington Monument 550 ft. high
Lunar Vehicle 370 ft. high

It is simple to cluster many horses for really big loads. Why replace the horse?"

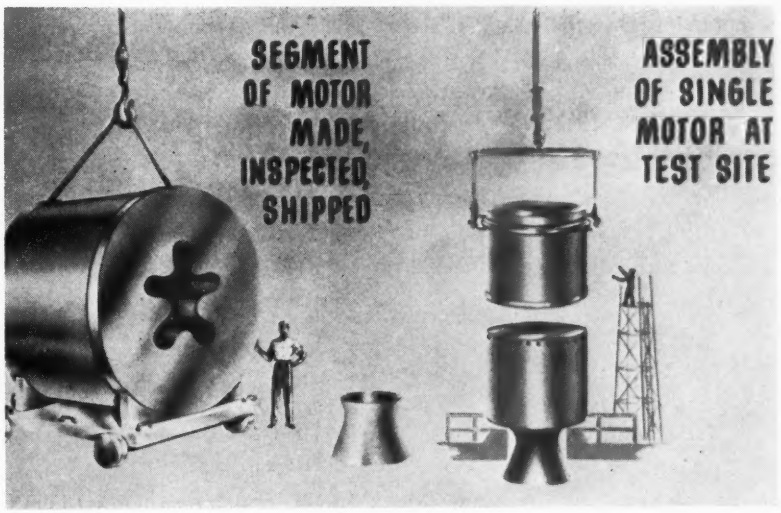
There may be a small element of the Everest Syndrome hidden deep in the solid-propulsion industry, but there are many better reasons leading to the use of solid rockets for space vehicles.

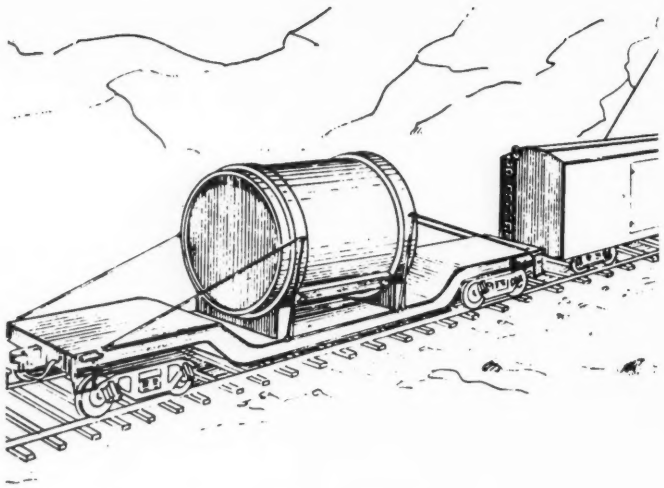
At this point, it may be instructive to review the historical background of the controversy about application of liquid and solid rockets. The controversy grows in part, I think, from the roots of the two industries. Briefly, solid rockets started small; liquid rockets started large. We have but to recall the 2.75-in. air-to-air solid rockets, the 6-in. bombardment rockets, the 5-in. air-to-ground rockets, to see the nature of the solid-rocket background. Because it started small, the solid rocket, in the minds of some, has been considered suitable only for "small" missions.

The liquid rocket started large. The first truly operational system is represented by the V-2 size. Part of the reason for the large start may be the relative difficulty of maintaining a good propellant mass fraction in very small systems which use pump feed. In any event, "big" missions have been considered natural for liquid-propellant rockets.

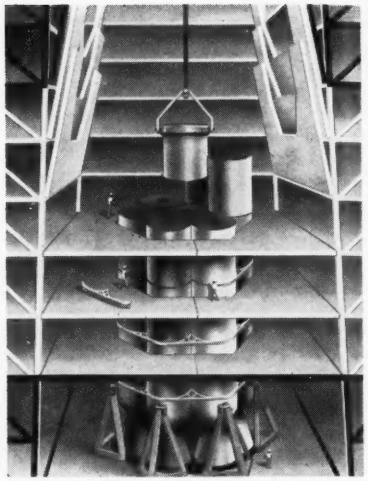
I don't have to remind you that the solid-propellant rocket is overcoming its small beginnings. Solid-propellant Pershing will replace liquid-pro-

Segmented Motor Concept





Transporting Motor Segments by Rail



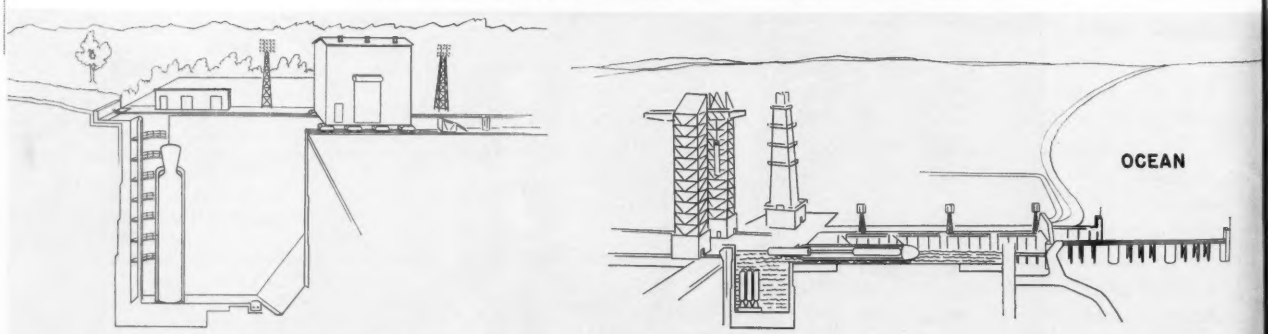
Assembling Segments at Launch Site

pellant Redstone; solid-propellant Minuteman will compete with liquid-propellant Atlas; solid-propellant Polaris does a job that cryogenic liquid missiles can't do at all.

What led to these changes? The great and basic virtue of the solid-propellant rocket is its simplicity. From this springs those valuable byproducts: Reliability and low cost. The solid rocket is simple because the complex operation needed to combine the reactive components in proper proportion has been done back home in the factory. The parts that were faulty have been screened out; the poor pieces have been detected and repaired or removed. In the liquid rocket, on the other hand, this process occurs in the vehicle itself. The machinery and equipment to bring the propellant components together in just proportion at the proper rate are here on the rocket motor. If machinery fails, as machinery always does, the liquid motor fails. If the mixer in the solid-propellant plant fails, the machine is stopped, a new mixer is started, and the end product, the rocket motor, is in no way affected.

But what about energy content, or specific impulse? Unquestionably, the liquid-propellant combination considered for the booster stages of space vehicles has about 7% more available energy than the corresponding solid propellants. This means the solid-propellant motor must use more propellant. I think I will show in this paper that this requirement is of minor importance when compared to the advantages of the reliable, relatively economical solid rocket. Note that the military services have apparently reached the same conclusion. I want to make it clear at this point, however, that the solid-rocket motor I discuss here is not a competitor with liquid hydrogen-liquid oxygen systems. For the specific applications where the very high specific impulse of this combination can be used, the solid-pro-

Water Handling Technique for Unsegmented Motor



Left, casting basin and test stand. Right, delivery and preparation for launch.

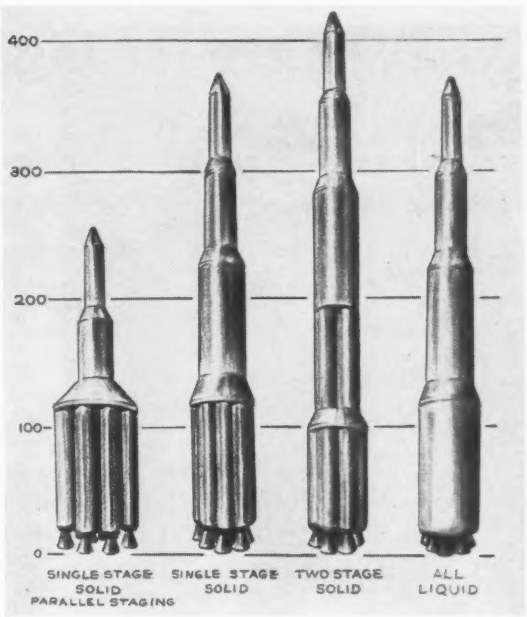
pellant rocket will be competitive only when the newest high-energy solid systems have been successfully tamed.

Shortly after the formation of NASA by the Space Act of 1958, the Agency's Solid Propulsion Organization initiated study programs to define more exactly the characteristics of solid-propellant boosters for space launch vehicles. The basic questions to be considered were these: Is it possible to make solid-rocket motors large enough to perform these massive boosting jobs without developing completely new propellants, control systems, and structures? Furthermore, if it is possible, how does the cost compare to the equivalent liquid-propellant booster systems?

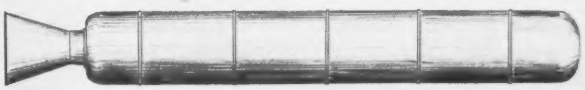
NASA's first study contracts were with Lockheed's Missile and Space Div. (Contract NASw-60) and with Ford's Aeronutronic Div. (Contract NASw-43). These studies were completed late in 1959 and indicated that it is feasible from a performance standpoint to make solid-propellant rocket motors to meet the requirements of boosters for space vehicles. The propellants for these missions need have specific impulse no greater than that already developed for vehicles like Polaris or Minuteman. The fabrication materials and technology need be no more advanced. These studies showed some benefit resulting from the flexibility of thrust-level capability for the solid rockets; more specifically, they showed that the optimum thrust level for a given launch vehicle lay in a range easily accesible to solid-propellant rockets. Proper choice of the thrust-to-weight ratio for the vehicle results in minimization of gravity loss, which can be a large and important factor in space vehicles. This is shown in the graph on page 00. In these studies, the optimum value of thrust-to-weight was shown to be about 3:1.

One specific vehicle examined in the studies weighed approximately 1 million lb at launch and had a solid-propellant first stage weighing approximately 400,000 lb. This (CONTINUED ON PAGE 50)

Nova Vehicle with Solid-Propellant Stages

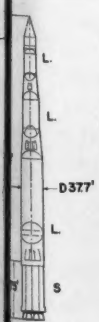


Basic Motor for Lunar Vehicle Solid-Propellant Booster



Gross Weight 1.3m lb. Segment Weight 231,00(
Overall Length 120' Segment Length 19.5'
Diameter 160"

Designs from Second NASA Study Program



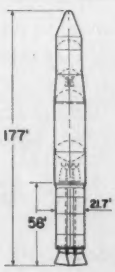
AEROJET GENERAL

PAYLOAD 168,700 LB
TO ESCAPE VELOCITY

TOTAL WEIGHT 7,550,000 LB

O_2-H_2 UPPER STAGES

SOLID PROPELLANT STAGE
WT. P. 3,710,000 LB
THRUST 13,920,000 LB
7 MOTORS EACH 140" D



GRAND CENTRAL ROCKET

PAYLOAD 60,000 LB IN 300 MI ORBIT

TOTAL WEIGHT 1,393,000 LB

O_2-H_2 UPPER STAGES

SOLID PROPELLANT STAGE
WT. 855,000 LB
THRUST 4.0 M LB
3 MOTORS 1.33 LB THRUST EACH
WT EACH 281,687 LB

THIOKOL

PAYLOAD 128,000 LB TO ESCAPE

TOTAL WEIGHT 8,735,000 LB

SOLID:
WT 2,167,000 LB
THRUST 9.96 M LB
3 MOTORS, 14.2' D

SOLID:
WT 5,055,000 LB
THRUST 21.14 M LB
7 MOTORS, 14.2' D

What costs for big boosters?

Space booster systems based on cryogenic oxygen and hydrogen emerge with a clear economic edge over competitive liquid and solid systems from this analysis

By James Schad

ARTHUR D. LITTLE, INC., CAMBRIDGE, MASS.

James Schad, a senior staff member at Arthur D. Little, Inc., heads a project on meteor research, and, since joining the company in 1953, has been largely concerned with small tactical rocket developments and missile-system studies. Before joining ADL, Schad was with Douglas Aircraft and General Electric working on Nike and Hermes. He received a B. S. in chemical engineering from Johns Hopkins Univ. and has done graduate work at Union College and Northeastern Univ.

IN THE early stages of scientific programs, operating techniques usually must be selected on the basis of technical feasibility. As programs advance, there often become available several adequate operating techniques, and the possibility of choice among them on other than strictly technical grounds. Very often in large projects money is the final question. This appears to be the situation with large rocket boosters, where there are today several propulsion and propellant systems in development from which the systems planner can make a selection.

We would like, in this paper, to compare the economics of various propellant combinations that could be considered for use in first-stage boosters of large rocket systems. We will assume that the cost of the rocket system proper can be used as a basis for system selection, if the other factors, such as handling costs, launching costs, reliability, etc., are in general equal.

An accurate estimate of the manufacturing cost of a large missile is most difficult to obtain. For some applications, cost can be estimated by adding the price of the components to the cost of assembling them. Unfortunately, these figures are usually unknown when the systems planner estimates the cost of future projects. For his purposes, less accurate but more easily obtained estimates are needed.

Costs in Terms of Propellants and Structures

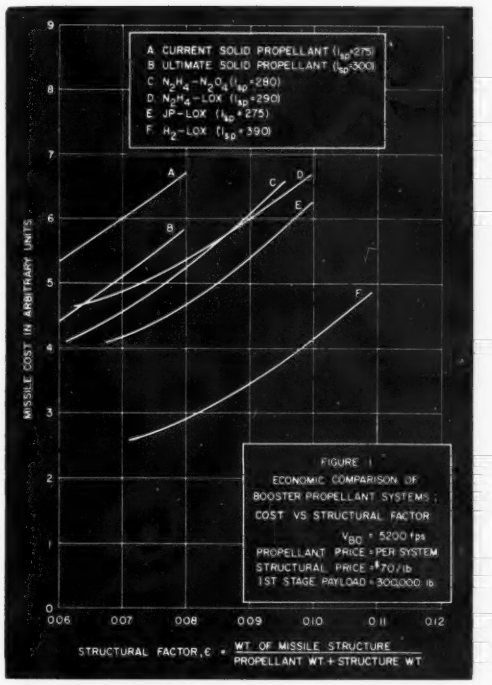
Simple factors will be used here that make the total cost proportional to the weight of major system elements.

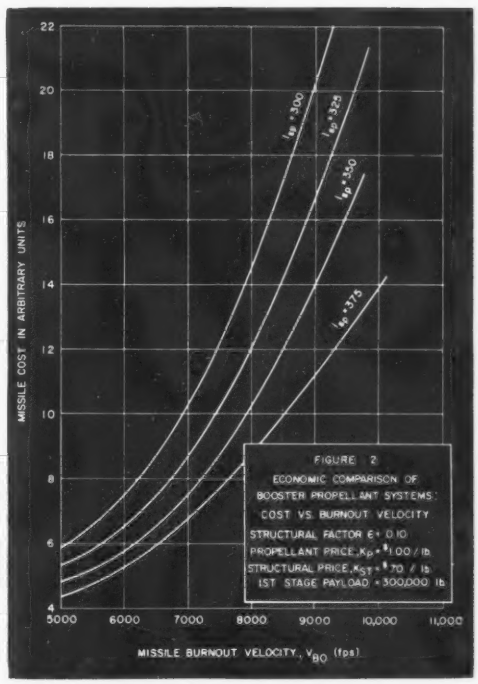
For instance, these simple cost factors have been applied to produce the comparison shown on page 27—relative missile cost plotted as a function of structural factor for various propellant combinations. The mission consists of boosting a 300,000-lb payload to a burnt velocity of 5200 fps in vertical drag-free flight. A JP-LOX booster for such a mission would be about the size of 1.5-megapound-thrust Saturn.

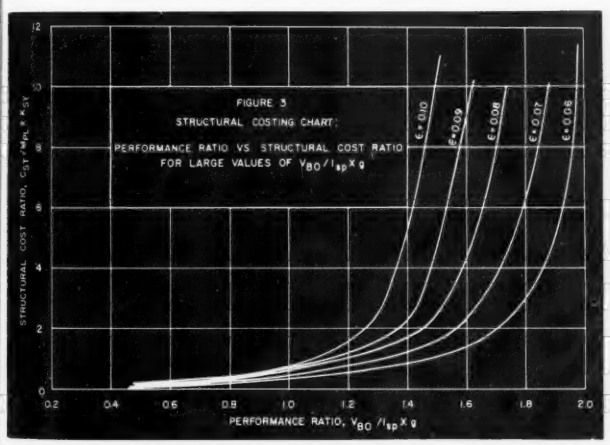
This graph reveals several important economic features of large booster systems:

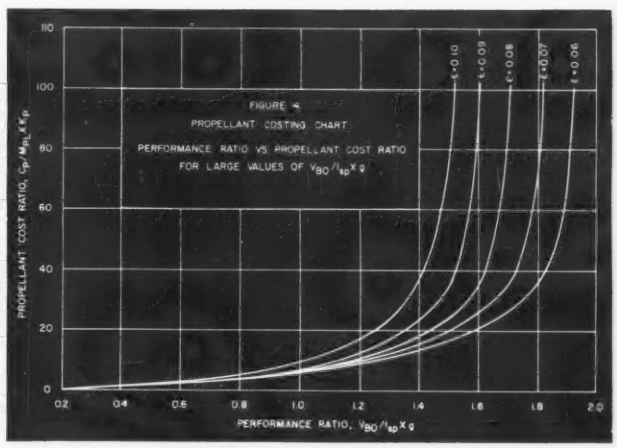
1. The liquid hydrogen-liquid oxygen combination is the only propellant that is likely to provide markedly more economical propulsion than the JP-LOX combination presently used in large rock-

Economic Comparison of Large Booster Rocket Systems


A. CURRENT SOLID PROPELLANT (I_{sp}=275)
B. ULTIMATE SOLID PROPELLANT (I_{sp}=300)
C. $N_2H_4-N_2O_4$ (I_{sp}=280)
D. N_2H_4-LOX (I_{sp}=290)
E. JP-LOX (I_{sp}=275)
F. H_2-LOX (I_{sp}=390)
MISSILE COST IN ARBITRARY UNITS
STRUCTURAL FACTOR, ε = WT. OF MISSILE STRUCTURE / PROPELLANT WT. + STRUCTURE WT.
FIGURE 1
ECONOMIC COMPARISON OF BOOSTER PROPELLANT SYSTEMS; COST VS. STRUCTURAL FACTOR
V_{BO} = 5200 fps
PROPELLANT PRICE = PER SYSTEM
STRUCTURAL PRICE = $70/lb
1ST STAGE PAYLOAD = 300,000 lb







ets. The economic advantage appears to exist even when other combinations are assigned the most optimistic structural efficiencies. The advantages of the H_2-LOX combination results largely from the high specific impulse of the propellant. It is very logical to recommend the liquid hydrogen-liquid oxygen propellant system for development in large booster engines.

2. The hydrazine propellants do not provide sufficient performance advantages over the JP-LOX propellant to offset the increased cost resulting from the high price of hydrazine. The latter would need to be reduced to less than 25¢/lb for those materials to be economically competitive with the JP systems. Hydrazine-fueled rockets will never be economically competitive with H_2-LOX systems; the selection of hydrazine as a fuel for large rockets must be made on grounds other than vehicle cost.

3. The best-performing solid propellants are not likely to provide economical propellant systems unless their price is drastically reduced. Even ascribing superior structural (CONTINUED ON PAGE 56)

An orbital air-scooping vehicle

Among the interesting possibilities for extended orbital operations is an air-scooping "filling station" for space vehicles

By Morton Camac and Felix Berner

AVCO-EVERETT RESEARCH LABORATORY, EVERETT, MASS.

Camac

Berner

Morton Camac is a major contributor to the space propulsion efforts of the Avco-Everett Research Laboratory, developing ideas which will lead to a research program aimed at the design of space propulsion systems. Since joining the Avco Everett Research Laboratory in 1956, he has been conducting research in dissociation and recombination of high-temperature gases and in X-ray and ultraviolet radiation. At Cornell Univ. where he received his Ph.D., Dr. Camac experimented with three high-energy particle accelerators and calculated neutron protron scattering cross sections. For his thesis he measured electron pair production by electrons. While with the Manhattan Project he assisted in the operation and maintenance of a cyclotron and investigated and identified several isotopes. At the Los Alamos Laboratory he handled large quantities of uranium and plutonium in the study of low intensity reactors to determine the nuclear properties of moderators and reflectors for fast reactors.

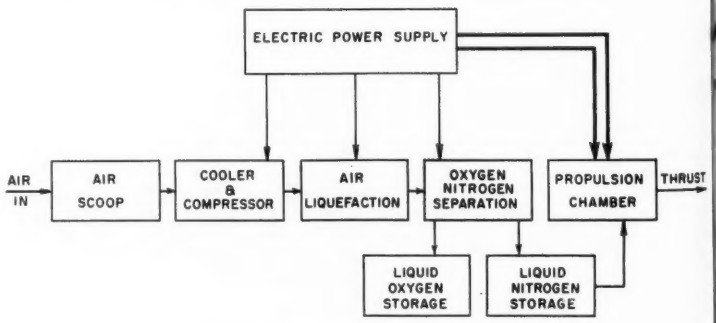
Felix Berner is a member of the staff of the Avco/Everett Research Laboratory, doing analytical work in aerodynamics and magnetohydrodynamic propulsion. Before joining Avco in 1957, he was associated with the Aerojet-General's Liquid Engine Div. in Azusa, Calif., where he performed feasibility studies of new air-breathing propulsion systems. He also has been associated with the Aviation Gas Turbine Div. of Westinghouse Electric and with Brown-Boveri Co., Baden, Switzerland. Berner received his diploma in machine engineering from the Federal Institute of Technology in Zurich, Switzerland in 1952.

IT IS generally assumed that the material required by spacecraft for propulsion will be lifted into orbit from the surface of the earth. But this need not be the only way to fuel spacecraft or to provide certain key materials for space operations. A satellite vehicle has the ability, we believe, to scoop air from the top of the atmosphere and from it to process and store liquid oxygen and nitrogen. These liquids could then be delivered to other spacecraft upon demand. Such an air-scooping vehicle would act as a "filling station" for spacecraft.

Liquid oxygen, nitrogen, or air obtained would have a variety of uses. For instance, liquid oxygen is used in chemical propulsion. In rockets using hydrogen as the fuel and operating close to the stoichiometric mixture ratio, the weight of oxygen may be more than 80% of the total propellant weight. The air-scooping vehicle would permit substantial increases of the payload weight ratio on many space missions by providing the oxygen which would be required beyond a low earth orbit. For example, a round trip to the moon, including a soft landing, could be achieved with a payload weight ratio of up to 40%. Payload weight ratio is defined as the ratio of the useful payload weight making the round trip to the weight that must be lifted off the surface of the earth.

In another area, nitrogen can be used as propellant in electrical-

Block Diagram of Air-Scooping Vehicle Components

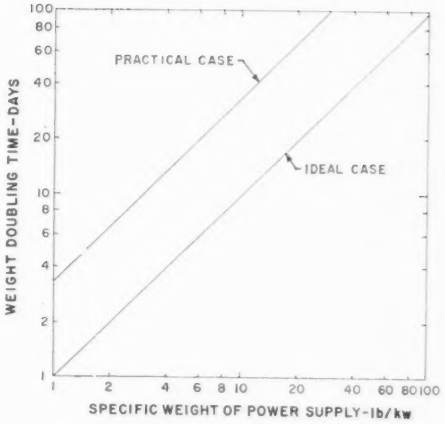


propulsion systems, such as magnetohydrodynamic accelerators of neutral plasma. It also has limited application in solar or nuclear-reactor heating systems. Then, air, especially its oxygen, is vital, of course, for inhabited space platforms and lunar stations. And it should be noted that atmospheric scooping with a satellite might also be practical on several other planets.

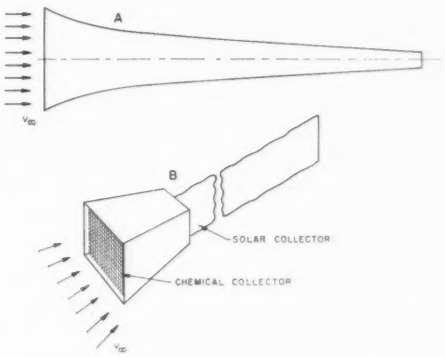
The use of the atmospheric gases for space propulsion have been proposed by several authors. In the oxygen ramjet, atomic oxygen, dissociated by solar radiation in the upper atmosphere, is recombined in a ramjet rocket.[1] However, there isn't enough energy available to make this a practical propulsion system. Rocket propulsion using liquid hydrogen and air has been proposed in the Lace system.[2] This method for air collection is practical when the flight speed is less than half the satellite velocity. S. T. Demetriades proposed the Profac space vehicle, which would liquefy air from the top of the atmosphere for subsequent use for space propulsion.[3] The air-scooping vehicle proposed in this paper is basically similar to the Profac vehicle.[4] We have investigated the vehicle design specifications to obtain the most economical air-collection system. This vehicle would only act as a space "filling station," and no consideration is given to other possible space missions.

The essential components of an air-scooping vehicle are shown in the block diagram on the opposite page. The vehicle moves along in a satellite orbit low enough that atmospheric gases can be collected at a reasonable rate and high enough so that aerodynamic heating is not serious. The air enters at the front of the vehicle through its scoop. In the range of altitude for practical scooping, the pressure of the decelerated gas is considerably less than that required for liquefaction; thus, an air compressor must precede the liquefaction machine. Air, once liquefied, could be stored as is, or the liquid oxygen and nitrogen separated and stored individually in insulated containers.

The scooped air exerts a drag on the inlet of the vehicle, because the gas is accelerated to the satellite velocity. There is an additional drag, due to pressure and viscous forces, which acts on the outer wall of the vehicle. The total resultant drag must be balanced by a thrust supplied by the vehicle, so that a constant satellite orbit can be maintained (CONTINUED ON PAGE 70)

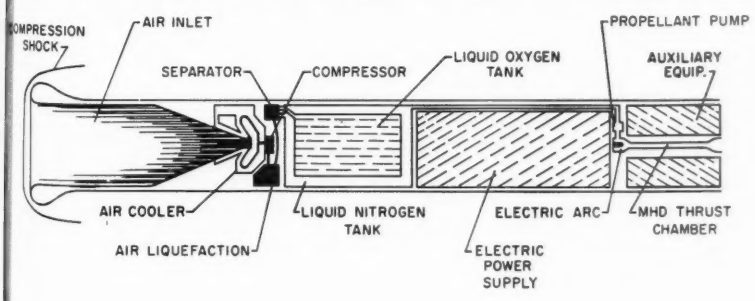


The weight-doubling time in days as a function of the specific weight of the power supply in lb/kw for an air-scooping vehicle operating in a circular orbit. The ideal case corresponds to no drag on the vehicle other than that from scooped gas.



Air scooping vehicle shapes—"A" showing nuclear-powered vehicle which would operate from approximately 320,000 to 360,000-ft altitude, "B" showing a solar-battery-powered satellite operating at about 550,000-ft altitude.

Air-Scooping Design with Nuclear Reactor as Energy Source



First IAF Congress for U.S.

Over 750 delegates from 30 nations expected . . . Charter flight from Sweden planned . . . Opening ceremonies at the Smithsonian

THE FIRST IAF Congress ever held in the United States is expected to draw over 750 delegates from 30 nations as representatives of the 37 member societies in the International Astronautical Federation. This year's meeting, the XIIth International Astronautical Congress, will be held at the Marriott Twin Bridges Motor Hotel in Washington, D.C., October 2–7. The American Rocket Society will be host for the Congress.

The Swedish Interplanetary Society has arranged a charter flight for its members and for the members of other societies in neighboring European nations.

The site of the Opening Ceremony, to be held Monday evening, October 2, will be the Smithsonian Institution. Immediately following the Opening Ceremony a reception will be held by the Air Force Office of Scientific Research at the Pan American Union Building.

The Plenary Sessions will be held at the Georgetown Univ. Institute of Languages and Linguistics. Modern IBM equipment will be available in the Institute's Multi-Lingual Room for immediate translation of the proceedings into several languages. The room has an over-all seating capacity of 115, and features a large horseshoe-shaped table accommodating 50 persons.

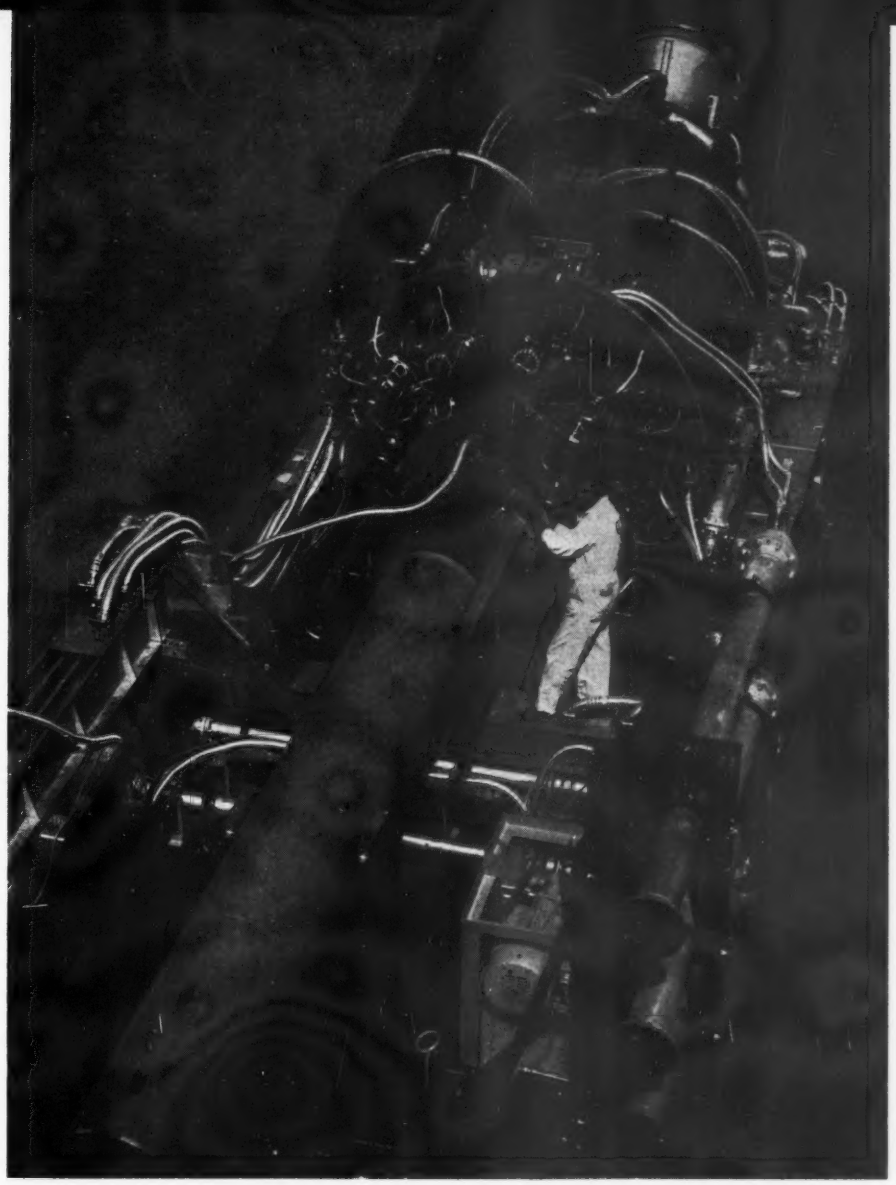
Samuel Herrick of the Univ. of California chairs this year's IAF Congress. The technical program will consist of formal paper presentations and round-table discussions. ♦♦

XIIth INTERNATIONAL ASTRONAUTICAL CONGRESS SCHEDULE

Washington, D.C.—October 2–7, 1961

	Sunday Oct. 1	Monday Oct. 2	Tuesday Oct. 3	Wednesday Oct. 4	Thursday Oct. 5	Friday Oct. 6	Saturday Oct. 7
MORNING		Plenary Session	International Academy of Astronautics Astrodynamics & Guidance Roundtable Space Propulsion Institute of Space Law	Space Physics Roundtable Combustion Session Institute of Space Law Bioastronautics Session I	Mt. Vernon 10:30–4:00	Space Communications Roundtable Vehicles Session Plenary Session General Papers Session	Sightseeing—Plants in Washington Area Goddard Field Trip
AFTERNOON		Plenary Session Ad Hoc Life Sciences Committee Meeting	International Academy of Astronautics Energy Conversion Astrodynamics & Guidance Institute of Space Law	Bioastronautics Session II Roundtable Space Physics Roundtable Institute of Space Law		Instrumentation Roundtable Bioastronautics Roundtable Structures Roundtable General Papers Session	
EVENING	Mixer	5–6:30 p.m. Opening Ceremony Smithsonian Institution Reception AFOSR—at Pan Am. Union Building	NASA Reception	National Gallery* Reception 8:30–10:30	Reception 7:00–8:00 Banquet 8:00	Open house Embassies*	

* Tentative



TORY II–A TEST VEHICLE

Specialist Conference Report

ARS-ORNL SPACE-NUCLEAR CONFERENCE

MAY 3–5, 1961
Gatlinburg, Tennessee

Discussions of low-power nuclear rocket engines and low-thrust flight problems, unclassified rundown on Pluto, and full-scale review of electric propulsion highlight May 3–5 meeting at Gatlinburg attended by 500

By Jerry Grey

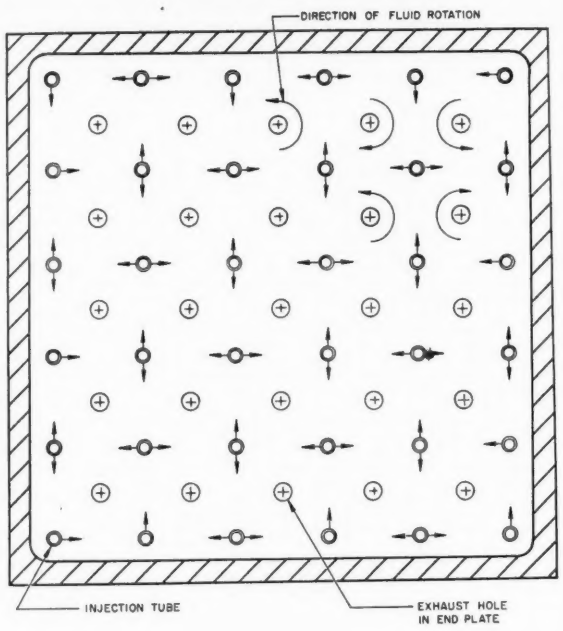
FORRESTAL RESEARCH CENTER, PRINCETON UNIV., PRINCETON, N.J.

THE SPACE NUCLEAR CONFERENCE, co-sponsored by ARS and the Oak Ridge National Laboratory and held in Gatlinburg, Tenn., May 3–5, drew an attendance of about 500 to the picturesque resort city in the heart of the Great Smokies.

The meeting produced a total of eight technical sessions at which more than 40 papers were read, three luncheons and a banquet, and a special evening session which drew an audience of well over 1000 to hear Wernher von Braun, director of NASA's George C. Marshall Space Flight Center, discuss the NASA propulsion program.

Discussions of low-power nuclear rocket engines and low-thrust flight problems, radiation and shielding problems, an unclassified report on progress to date in the Pluto program, and full-scale reviews of electrical propulsion and controlled fusion research, were among the highlights of the conference.

Cross Section of Vortex Matrix



Keynotes in Cosmology

The opening session of the conference, designated the "keynote," consisted of a welcoming address by A. M. Weinberg, director of ORNL, a brief introduction by session chairman Howard S. Seifert, and three papers: "Nuclear Clues to the Early History of the Solar System," by W. A. Fowler, "Biological Experiments in Space," by C. Tobias and J. Slater, and "Frontiers of Astrophysics," by B. Stromgren.

Although all three of these papers were of considerable merit in their own right, their presence as "keynote" talks appeared to leave a rather large and obvious gap in the space-nuclear subject, namely, the technology of nuclear space systems. (A scheduled paper on this subject by Krafft Ehricke was cancelled, but it is doubtful that it could have covered the entire omitted area.) A significant keynote subject might have been the expected major effects of nuclear power on the technology of existing spacecraft and missions, e.g., propulsion systems, vehicles, crew safety problems, ground support, probe experiments, mission design, etc. Fortunately, many of these topics were covered later in the conference program.

The Fowler paper was a crystal-clear, beautifully presented exposition of the use of simple nuclear reasoning coupled with isotopic abundance measurements to develop a theory of formation of the solar system. Based on the relative abundance of the light elements and their isotopes (hydrogen, lithium, beryllium, and boron), Fowler, Greenstein, and Hoyle showed that the required condi-

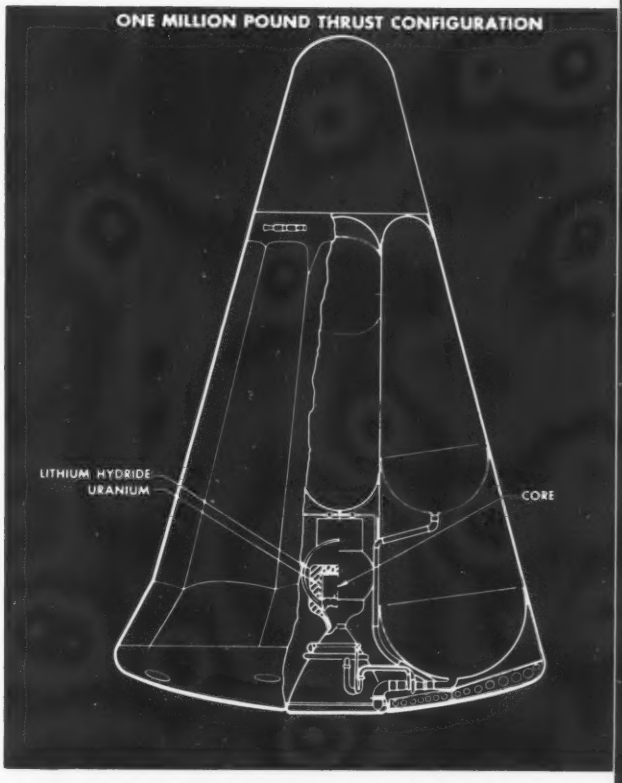
Flight Test Schedule—Electric Propulsion Units

	1962	1963	1964	1965
Arc Jet Engines	1	3	2	1
Ion Engines	3	10	7	2
MPM Engines	-	1	3	3
SCOUTS	2	7	6	3
Arc Jet Engines		1	1	-
Ion Engines		1	2	1
MPM Engines		-	1	1
AGENAS OR CENTAURS		1	2	1
Arc Jet Engines				1
Ion Engines				1
MPM Engines				-
CENTAURS				1

tions were satisfied during the solar system's formation by the existence of small "planetesimals" 1–50 m in diam which later coalesced to form the planets.

A method of performing quantitative analyses of the light-element content in lunar or planetary surfaces by simple elastic reflection of high-energy protons was also described. Coupled with the nuclear "detective work" discussed, space experiments of this type could provide us with a wealth of information on solar-system formation. This would appear to be a useful experiment for future soft-landing probes on the Moon, Mars, and Venus.

The Tobias-Slater paper reviewed space biological experiments to date, as well as ground-based experiments, and suggested experiments which might be performed in future missions. Of special importance, they noted, were experiments involving long periods of weightlessness, since there were already some indications that physiological deterioration might result from prolonged exposure to zero-g or near-zero-g conditions, and the accumulation of biological data on space radiation and its effects.



Configuration selected by Trapp and Wilson in study on "Optimizing Reactor Shield, Propellant Boiloff, and Tank Pressure."

Astrophysics Reviewed

The final paper of the opening session was an excellent summary of the state of knowledge on stellar energy transformations, interstellar matter, and characteristics of other galaxies. The possible value of orbiting observatories was discussed in the light of this knowledge. For example, the opportunity of observing stellar spectra at wavelengths below 3000 Å, impossible on earth due to atmospheric absorptions, will permit far greater detail in the analysis of stellar structure. This feature will also provide for measurement of the relative contents of molecular and atomic hydrogen in space.

The first afternoon was split into two sessions, one on advanced propulsion concepts, the other on high-temperature reactor technology. Considering first the session on advanced propulsion, chaired by Frank Rom, the first paper, by S. Nelson, was devoted to the "Plasma Core Reactor." This was a rather naive rehash of the field-contained fission cavity reactor, in which ionized fissionable fuel inside a solid reflector "cavity" is kept in place by "magnetic mirror" field geometry while gaseous hydrogen, passing over the plasma regions, is heated and expelled as propellant. The analysis included some seriously questionable areas, e.g., neglect of the collisional diffusion mechanism which probably dominates the diffusion process, total lack of consideration of the energy-transmitting process between the fuel and propellant, etc. The second paper, "The Vortex Matrix Approach to Gaseous Nuclear Propulsion," by M. L. Rosenzweig, was a review of the multiple-vortex concept and its effect on the gaseous-core reactor's nemesis: turbulence. Rosenzweig stated that the vortex matrix (illustration or page 32) reduces turbulence by eliminating the soil boundaries between individual vortex tubes, thus eliminating the turbulent boundary layers and also reducing viscous dissipation. The paper was principally a review of the fluid mechanics of vortex containment and of the vortex matrix idea presented in earlier publications. One basic consideration *not* discussed in the paper was the unavoidable effect of the heat addition itself in generating high turbulence levels.

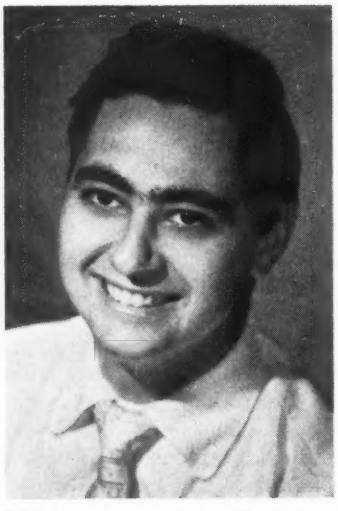
"The Separation of Tungsten 184," by S. A. Levin, D. C. Hatch, and E. Von Halle, considered the possibility of increasing the concentration of tungsten 184, which has a capture cross-section for thermal neutrons of 2 barns as compared with the 18 barns of natural tungsten. With pure tungsten 184, it would be possible to use the design of the nichrome HTR3 direct-cycle turbojet reactor configuration at rocket temperatures by switching to tungsten as the structural material. The authors proposed that the required concentration of W-184 be obtained by the gaseous diffusion process now used to separate U-235 from natural uranium. Samples with capture cross-sections in the 3–7 (CONTINUED ON PAGE 61)

Applications for low-power nuclear rockets

Fast-reactor nuclear rockets offer high performance in many missions starting from orbit with a 25-ton vehicle

By Ralph S. Cooper

LOS ALAMOS SCIENTIFIC LABORATORY, LOS ALAMOS, N.M.



Ralph S. Cooper began his professional career as a herpetologist (at age 14) and moved on to chemistry and chemical engineering, obtaining a B.Ch.E. from the Cooper Union in 1953. Graduate work in physics at the Univ. of Illinois led him to an M.S. and Ph.D. Dr. Cooper has done research in solid-state physics, electrode processes, optics, and ionic diffusion and transport. Several papers based on his thesis were published in the *Journal of the Electrochemical Society*, one of which won the Journal's Young Author Award in 1956. Upon receiving his doctorate in 1957, Dr. Cooper joined the Theoretical Div. of Los Alamos Scientific Laboratory, where he has been concerned with reactor physics and many phases of the nuclear rocket program, including mission studies.

IN MANY discussions of nuclear rocket propulsion, it is often stated or implied that the minimum weight of the engine will be high because of the reactor, and it is consequently concluded that the nuclear rocket will be applicable only to quite large vehicles. We wish to show that this is not the case, and to present results for a fast-reactor engine concept which has a wide variety of promising uses in the low ($<$2000 mw) power range. The engine concept in question—the tungsten-based fast reactor—has been discussed by William R. Corliss in his book, "Propulsion Systems for Space Flight" (McGraw-Hill, 1960, page 157). These results will be compared to those for graphite-moderated reactor and chemical (O_2-H_2) engines. We will also discuss shielding requirements for fast reactors and the effects of shielding upon vehicle operations.

The high operating temperatures of a nuclear-rocket reactor restrict the choice of fuel elements for it. Graphite has long been a common choice for many reasons; but to make a small reactor with graphite as fuel element and moderator, we are limited by achievable uranium loadings and criticality considerations to rather large minimum weights.

It is well-known that for unmoderated systems (called "fast," owing to the high average neutron velocity) quite small critical assemblies are possible—ones weighing as little as 50 lb.[1] Thus, for a fast-reactor rocket the problem is not so much achieving criticality as finding suitable fuel-element materials.

Two fissile refractory compounds are immediately apparent—uranium oxide, UO_2 (MP of 2800 C), and uranium carbide, UC (MP of 2450 C). The UO_2 might be dispersed in a refractory metal such as molybdenum (MP of 2600 C) or tungsten (MP of 3370 C) to obtain structural strength and containment of the urainum. Uranium carbide reacts with these metals, but forms solid solutions with other carbides to form higher melting materials—for example, with ZrC (pure ZrC melts at 3525 C).[2] The highest melting solids known are the carbides HfC, TaC (MP $\sim$ 3800 C), and 4 TaC = 1 HfC (MP = 3930 C).[3] Because of their large thermal and resonance absorption cross sections, these carbides are best suited to fast reactors. Such compounds, alloyed with UC, offer hope of producing appreciable hydrogen dissociation in solid-core reactors.

Thus, fast reactors include possibilities for either low weight or

high specific impulse. The fast reactor materials are quite dense, and lead to small cores ranging from 10- to 20-in. in diam. If desired, heavy-element (e.g., nickel) reflectors, which also act as radiation shields, can be used in place of the much lighter beryllium reflectors assumed for most cases here.

Different fuel materials and loading densities lead to various engine weights, but for our purposes we will make a representative assumption of 1000-lb minimum engine weight, plus 1 lb/mw of reactor power. There are other lightweight reactor concepts for which these assumptions may be applicable (e.g., a BeO-moderated, W^{184}-fueled reactor).[4] We assume an exit gas temperature of approximately 2200 C ($I_{sp} \sim 800$ sec) at which 1 mw corresponds to approximately 45-lb thrust. We obtain all of our data for graphite reactor engines from NASA-TN-D675, which is unclassified.[5] From this we obtain a minimum graphite reactor engine weight of 4500 lb, plus approximately 1 lb/mw of reactor power up to 2000 mw.

We shall begin with an application which can be most immediate, since the necessary boosters already exist. Since we cannot present details of our ICBM boosters here, we shall make arbitrary but reasonable assumptions concerning performance parameters of chemical rockets, as given in the table below, and compute results for a range of vehicle gross weights.

We shall compute payloads for Lox-RP boosters with upper stages powered by Lox-RP, Lox-H_2, fast-nuclear, and graphite nuclear reactors. The first-stage mass ratio is kept fixed at a value which is near optimum for the all-chemical systems. Optimizing the chemical-nuclear combinations would lead to disappearance of the chemical stage. In practice, the limiting factor on nuclear-stage size will be engine power level or H_2 propellant volume.

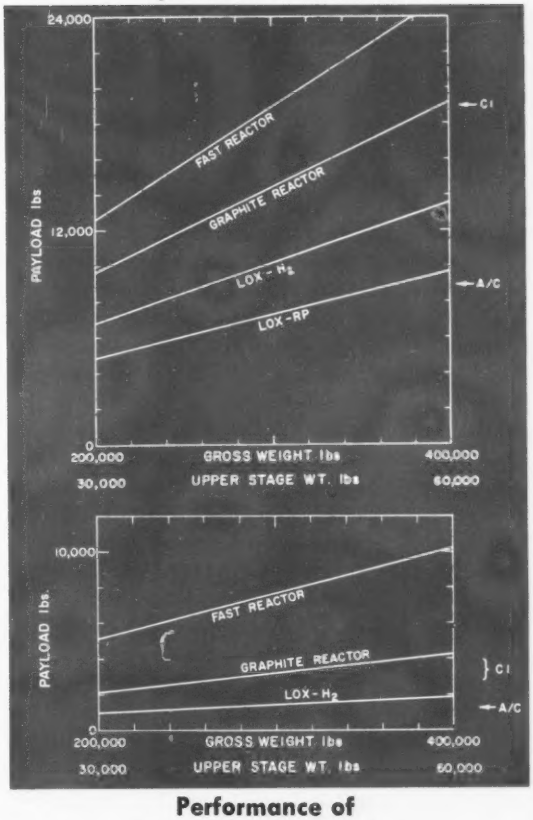
Here we will compare nuclear and chemical upper stages of the same gross weight and same fractional weight of the booster. Our first-stage

Typical Performance Parameters for Vehicles

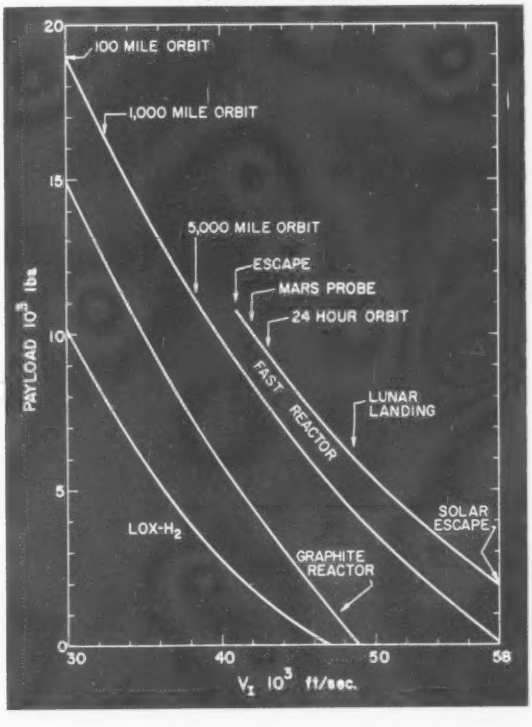
System	I_{sp} (sec)	$s = \frac{\text{Structural wt}}{\text{Gross wt}}$
Lox-RP	300	0.05
Lox-H_2	420	0.09
Nuclear	800	—

NOTE: Tank wt/H_2 wt = 0.1 and 0.15 (including insulation, stiffeners, etc.). Engine wt/gross wt ≈ 0.04 (fast reactors). and ≈ 0.14 (graphite reactors). Additional structure, guidance, control, etc. = 0.02 gross wt. Thrust/weight = 1.0.

Performance of Representative Vehicles



Performance of a 300,000-lb Vehicle



mass ratio will be 5.0, which leads to upper stages weighing 15% of the gross takeoff weight and to a first-stage ideal velocity increment of 14,500 fps. The upper stages must supply approximately 15,500 fps to achieve a low earth orbit, and 28,500 fps for a 24-hr orbit or low lunar orbit, which have almost identical velocity requirements.

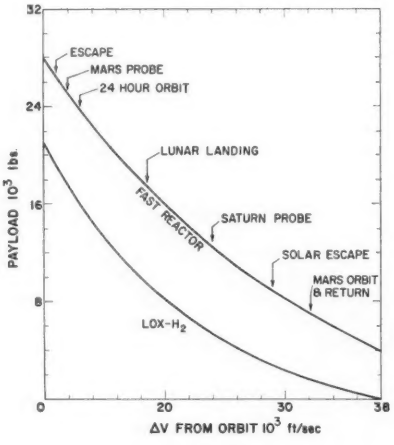
Results for these two missions are given in the two graphs on page 35, the payloads being proportional to the gross vehicle weights. We have used the very conservative value of 0.15 for H_2 tank weight fraction, though values of as low as 0.03 have appeared in the recent literature for this size tankage.[5] This value of 0.15 includes insulation, interstage structure, stiffeners, fittings, etc. which may be necessary to support a heavy payload and to stand the boost acceleration.

The graph on page 35 presents the payload vs. ideal velocity for a 300,000-lb vehicle (45,000-lb upper stage), indicating various missions. It can be seen that a vehicle composed of an ICBM-class booster with a fast-reactor-powered second stage would be very valuable for instrumented exploration of the solar system. Its performance exceeds that of the Saturn C-1 and approaches that of the Saturn C-2 for the more difficult missions, based on unclassified approximate performance figures. The reactor power level required is approximately 1000 mw, which would be useful for orbital start stages of at least 200,000 lb, as will be discussed later.

Next let us consider a small second stage designed as a development tool—to explore those aspects of nuclear propulsion which are not necessarily sensitively dependent upon reactor power or specific impulse—or for flight testing new engines. Consider a 20,000-lb nuclear second stage on a 180,000-lb booster (gross wt of 200,000 lb). Let us assume it to be a "poor man's" stage, with a 20% tank fraction, 8% miscellaneous dead weight, and engine operating at only 1500 C (I_{sp} = 700 sec) and placed in a higher orbit ($\sim$ 500 mi.) to avoid re-entry. Even under these conditions, with a 2000-lb reactor we have 5000 lb left over at burnout for payload instrumentation, return and recovery devices, or larger engine weight. We make no brief here for the desirability of such a stage, but we do for its technical feasibility as a relatively extreme case of a small nuclear stage with payload capability. One could probably be designed even for an IRBM booster, but there would be little point to it.

It has frequently been shown that thrust-to-initial-weight values of approximately 0.2 are sufficient for orbital operations with negligible gravitational losses. Thus, quite low powers (40 mw/10,000 lb) can be useful. Again considering a relatively extreme case, a 10,000-lb nuclear orbital stage operating at only 1500 C (I_{sp} = 700 sec) with a dead weight of 2500 lb (a 50-mw reactor could weigh 500 to 1000 lb) can out-perform a similar Lox-H_2 stage with 1000-lb dead weight. A stage of about this size could be placed in orbit by Atlas-Centaur and out-perform the two-stage vehicle by about 2000 lb of payload.

The case is stronger for a (CONTINUED ON PAGE 66)



Conditions and Performance in Missions Starting with 50,000-Lb Orbital Stage

The graph at left summarizes the data in this table.

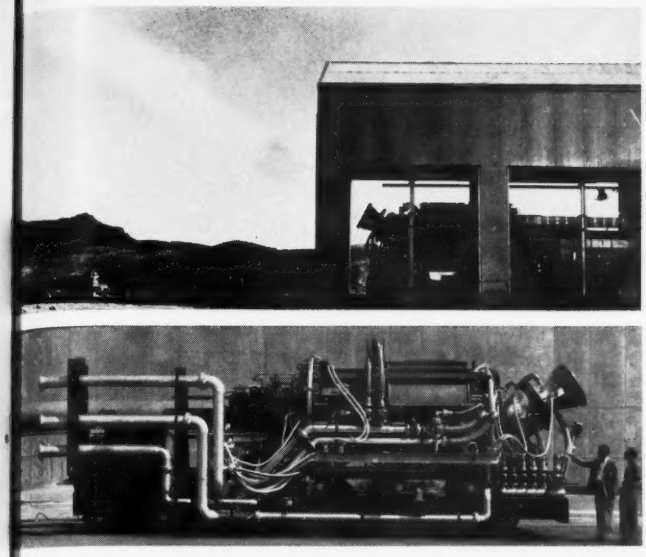
A. Assumptions

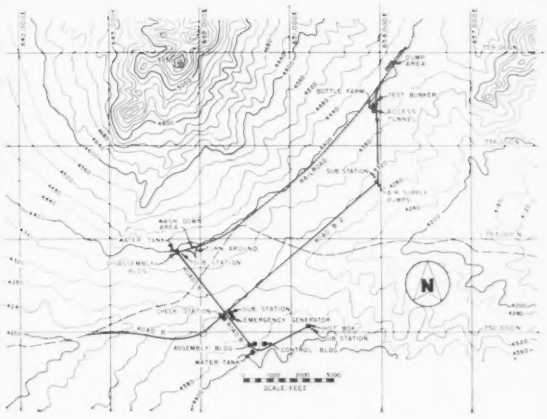
System	Lox-H_2	Fast Reactor*
I_{sp}, sec	420	800
Thrust, lb	20,000	20,000
Engine, lb	500	1,500
Tanks, insulation lb	1,500	5,000
Misc. dead wt, lb	1,000	1,000
Total dead wt, lb	3,000	7,500

B. Typical Results

Mission	ΔV, fps	Payload, lb	
		Lox-H_2	Fast Reactor*
Lunar orbit	13,000	16,000	23,700
Soft lunar landing	18,600	9,400	17,500
Solar escape	29,000	2,800	8,900
Mars satellite and return	32,200	1,600	7,000

* Graphite reactor results similar, except engine weight is 3500 lb greater, payload 3500 lb less.





Top left, Tory II-A in a test run with approximately 700 lb of air per second at 1600 F passing out the nozzle; above left, a closer view of Tory II-A; and above right, a map of the Nevada Test Site layout.

The Pluto program

Recent tests and a maturing nuclear technology bring a nuclear ramjet for missiles closer to realization

By Harry L. Reynolds

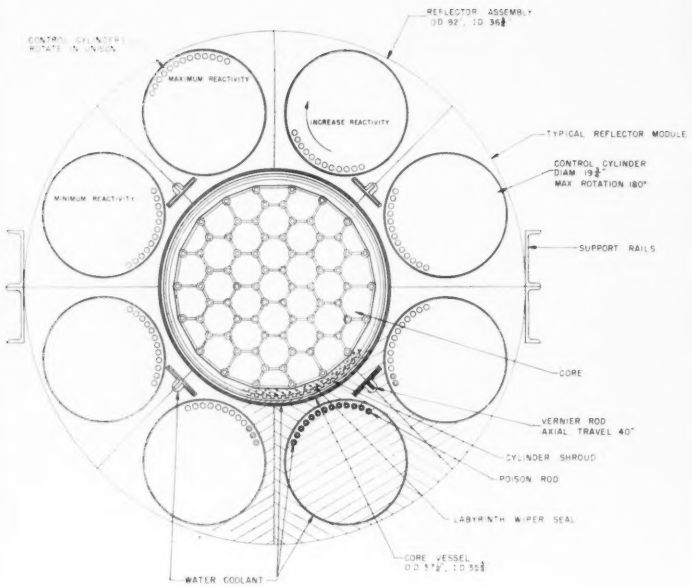
UC LAWRENCE RADIATION LABORATORY, LIVERMORE, CALIF.

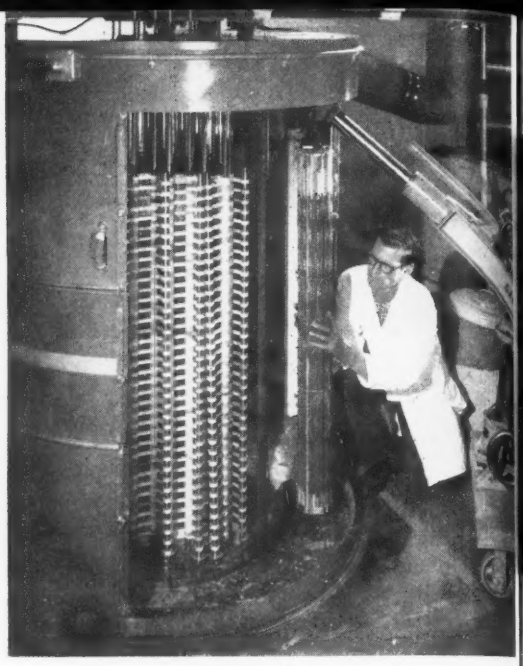
THE PLUTO program was established by the AEC to show the feasibility of a nuclear reactor which would be able to propel a supersonic ramjet missile. Feasibility has been defined as the successful ground operation for short times of a reactor with the desired characteristics, together with suitable laboratory experiments to allow extrapolation to the desired lifetime. With the exception of the lifetime and the expected missile accelerations, the reactor will perform on the ground in the same environment as expected in the missile flight.

Although the nuclear ramjet can be designed for flight at altitudes from sea level to over 100,000 ft, it possesses a unique ability for supersonic flight over long distances at sea level. Overcoming the supersonic missile drag at sea level requires a large amount of energy, which can be supplied only by a reactor if flight over significant distances is required. The present Pluto program is directed toward the design of a reactor for sea-level flight.

The nuclear ramjet consists of an inlet diffuser followed by a single-pass, straight-through heat exchanger (the reactor) and an exhaust nozzle. The purpose of the diffuser is to reduce the velocity of the intake air and recover as much of the ram, or stagnation, pressure as possible. In passing through the reactor, heat is added to the air. The random heat energy is changed into directed motion in the nozzle, resulting in an increase in air momentum and a net thrust for the missile. The sea-level nuclear ramjet develops a maximum thrust in the vicinity of Mach 3. This is illustrated in the

Harry L. Reynolds is assistant division leader of the Pluto project at Lawrence Radiation Laboratory. His background includes a doctorate in physics from the Univ. of Rochester in 1951, an AEC fellowship at the university from 1949–51, and a B.S. from Rensselaer Polytechnic Institute in 1947. During World War II, he served from 1944–46 in the U.S. Navy. Prior to coming to Lawrence Radiation Laboratory, Dr. Reynolds was a senior physicist at Oak Ridge National Laboratory from 1951–55.

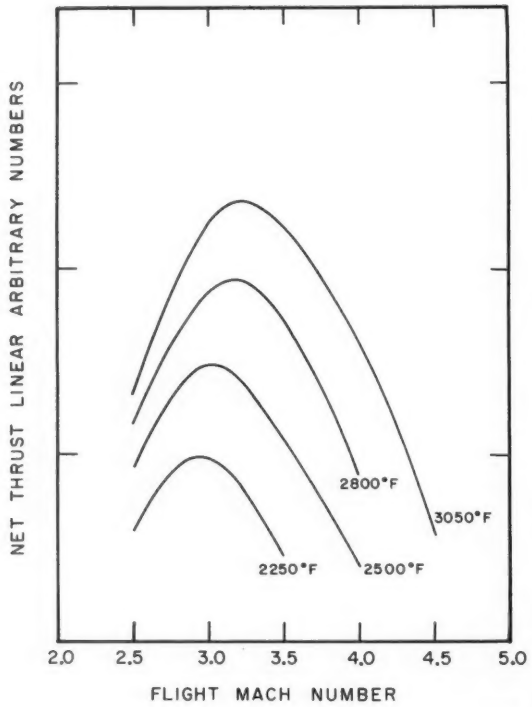




graph at left, where thrust is plotted as a function of the flight Mach number for several reactor temperatures. The design has been optimized at each velocity and temperature. It is apparent that the ramjet performance increases rapidly with temperature increase and that a Pluto reactor will be a high-temperature reactor by today's standards.

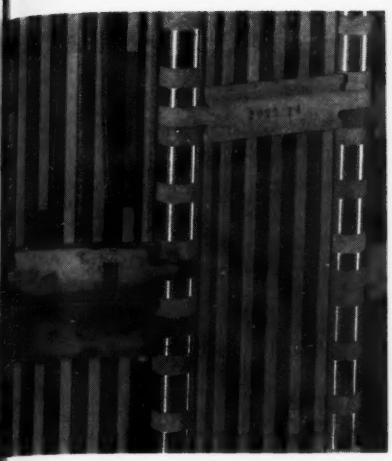
The choice of material for the reactor is severely restricted. The material must have reasonable strength and resist oxidation at elevated temperatures. In addition, it must be a good moderator and a poor neutron absorber. Moderating ability is required because a fast, unmoderated reactor would be prohibitively expensive in terms of nuclear fuel. The only material that can meet the requirements for the moderator is the ceramic, beryllium oxide. Uranium forms a refractory oxide, UO_2, which unfortunately turns to a volatile oxide at high temperatures in air. Cladding is impractical at these temperatures, and thus the fuel is mixed homogeneously with the BeO moderator.

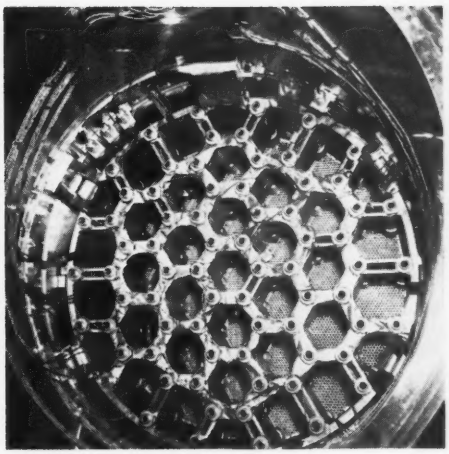
Nuclear Ramjet Performance

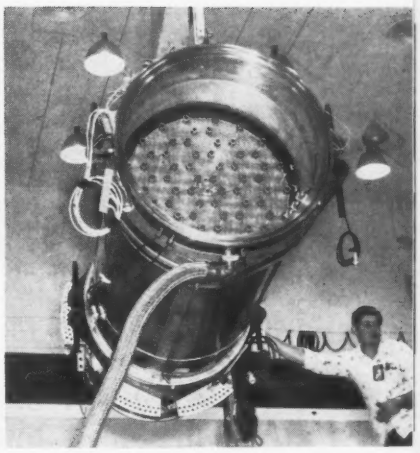


Reactor Neutronics

The reactor neutronics must next be considered. The Pluto reactor can be classified as an intermediate-energy one, which means that a large fraction of the fissions take place at neutron energies greater than thermal. This is a consequence of the small size of the reactor. The prediction of criticality for such a reactor is difficult, and much effort has been expended at the Laboratory in the development of computational methods and in critical experiments which allow the checking and normalization of the







Opposite page and above left to right, cross section of Tory II-A core and reflectors; core during assembly; outside of core; front of core; and fully assembled core in pressure vessel.

computations. Critical experiments have been done from room temperature up to 1200 F. Much of this work has already been reported by the writer in "High Temperature Critical Systems," *ARS Journal*, vol. 30, 1960, pp. 772–775.

A homogeneous reactor is by its nature rather slow to respond in temperature to power changes because of the large heat capacity of the fuel elements. However, power and temperature changes must be fast when compared to usual procedures for power reactors. Start-up times of the order of one minute are desired. Thus a considerable effort has been devoted to the reactor controls, kinetics, and automatic control systems.

The reactor radiation creates a problem due to the large gamma and neutron heating in non-nuclear components both in and near the reactor. As an example, power densities in metallic structures in the reactor can be several times larger than the power density in the fuel elements themselves. Also, radiation damage of some materials can have serious consequences. These problems are under investigation by computation and experiment.

The mechanical designer is faced with formidable difficulties. The pressure drop in the direction of the air stream results in a force of several hundred thousands of pounds tending to push the reactor out of the nozzle. In addition, accelerations of many g's due to air turbulence in flight must be reacted. The materials for supporting structures are limited in volume and nature because of neutronic requirements and high temperatures. Cooling air has a minimum temperature of 1000 F. The usual weight limitations are also present for structural elements. The fuel elements are ceramic and thus are brittle. Methods of design had to be utilized which did not rely upon ductility to take care of inevitable errors in fabrication and design.

After suitable laboratory experiments and tests, it was deemed desirable to attempt the solution of all of these problems—and others unmentioned, such as thermodynamics and fluid flow—in a reactor to be tested upon the ground.

For a Mach 3 sea-level ramjet, air is supplied to the reactor at a pressure of approximately 350 psi and a temperature of about 1000 F. Flow rates greater than 2000 lb/sec can be achieved. It is immediately apparent that the ground-test facility, and in particular the air supply, for such a reactor is large and complex. Also, a considerable amount of BeO is required for a full-scale reactor. At the beginning of the program, the fabrication of BeO was expensive and time-consuming.

Therefore, it was decided that the first ground test would be of a small reactor, so that the air supply and BeO requirements would be minimized. The small, high-temperature fueled core of this reactor would be tested to obtain data on the materials, physics, and engineering required for the design of the full-scale reactor. To enable the reactor to reach criticality, the core would be surrounded with a thick carbon reflector operating at room temperature. In addition, the reactor controls would be placed in this reflector so that the problem of operating control rods in a reactor at high temperature could be avoided in the first tests. The reflector with controls has no bearing whatsoever upon the missile reactor, since it is present only to satisfy neutronic requirements for the small test core.

(CONTINUED ON PAGE 72)

The drive for lifting re-entry vehicles

Our extensive and diverse program for achieving practical lifting re-entry vehicles brings a need for cohesive design work, applied research, and management

By R. E. Fredette and F. D. Orazio

AFSC AERONAUTICAL SYSTEMS DIV., DAYTON, OHIO

Fredette Orazio

Raymond E. Fredette, chief of the Aerospace Vehicle Design Integration Section of the Directorate of Advanced Systems at the Aeronautical Systems Div. in Dayton, Ohio, received his B.S. in aeronautical engineering from the Univ. of Notre Dame in 1954. His work in the field of preliminary design and evaluation has embraced aeronautical, ballistic, and re-entry systems.

Fred D. Orazio, asst. chief of the Advanced Systems Planning Office, Aeronautical Systems Div., received a B.S. degree in Mechanical Engineering-Aeronautical Option in 1934 from Carnegie Institute of Technology. After having worked in the automotive industry in Detroit on body design he joined the Engineering Div. Aircraft Laboratory at Wright Field where he was assigned to work in aircraft preliminary design. In 1945 he was made technical assistant to the chief of the Design Branch of the Aircraft Laboratory. In 1956 he was consultant for aircraft and propulsion for the Directorate of Development, and in 1957 became chief of the Systems Engineering Office concerned with systems analyses and integration of advanced military aircraft, missile, and space systems.

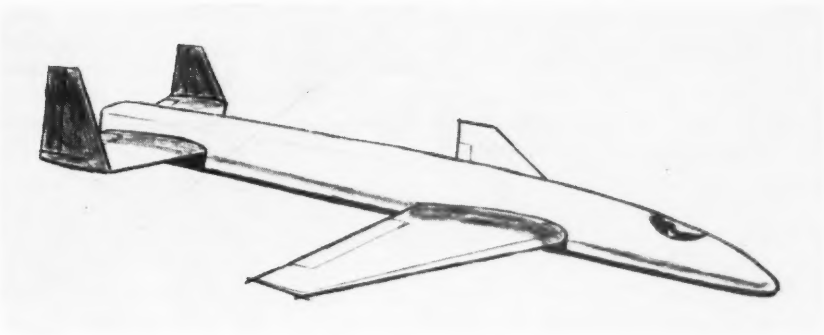
PERHAPS the first serious consideration given to lift as a means of re-entry was the German-generated idea of wings for the V-2 weapon. Calculation showed that the V-2 could realize a range extension of approximately 100 mi. by the addition of lift in the terminal phase of flight. Also, Eugen Sanger studied a concept involving winged rockets entering dense atmospheric layers. His work was aimed at showing considerable range gains by means of a ricocheting motion off of the atmosphere. Known as the "Antipodal Bomber," it would bounce off the atmosphere, coast to a higher altitude, return to the atmosphere, and skip off again. The dampening flight path continued to extend range until the velocity was sufficiently decreased to effect normal gliding flight and landing. It was postulated that aerodynamic heating could be alleviated in this manner, but a critical flight-control problem persisted.

In the early 1950's the then Bell Aircraft Corp. proposed a system called "Bomi," later referred to as "Robo," which considered a piloted-glider final stage for a rocket-boosted system. In addition to the problems of launch and staging with a winged payload mounted in tandem on the booster, hypersonic re-entry and glide became a serious engineering undertaking from the standpoint of aerothermodynamics, structures and materials, flight control, internal equipment, and human factors. The need for basic and applied research in almost every area of the flight-vehicle art was now apparent.

Challenge to Engineering Science

Developed today are outstanding aerodynamic vehicles, rocket-propulsion devices, and subsystem components. But important engineering achievements are now required in the field of re-entry, particularly lifting-re-entry design. Fortunately, in this important area of endeavor the United States can draw upon a background gained from many years of high-speed research vehicle development.

Lifting re-entry must be considered for application to any space system that requires physical retrieval. To what extent this mode of re-entry will be employed for future aerospace activity is largely determined by the state of the art of the major technical disci-



Design ideas for the V-2 and Eugen Sanger's concept of the antipodal bomber, sketched here, raised early questions about lifting re-entry.

plines that prevail at the time a particular system will be considered for development.

For instance, earth-to-earth delivery for our missile force was predicated upon pure ballistic re-entry because our knowledge of materials properties, and the re-entry induced environment, was more or less limited; expediency dictated a path of least resistance. The ballistic-missile re-entry bodies developed were straightforward, relatively low-risk designs.

Space Systems Call for Lifting Re-entry

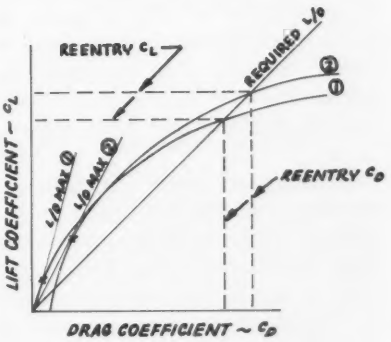
On the other hand, the time phasing and requirements of space systems presently envisioned seem to point to heavy reliance upon lift as a means of re-entry. At any rate, hardly a re-entry design proposal submitted today is without at least a cursory examination of lift to perform the mission.

In general, when manned occupancy, re-use, or combinations of these are important, there is a good probability that lifting re-entry vehicles will do the job better. The true value of lift configurations rests, however, in their ability to perform tasks that cannot be realized by other means. Cases wherein considerable atmospheric maneuvering, low decelerations, and conventional airplane-like landing capabilities are the sought-after performance characteristics require a lifting-re-entry approach as the only reasonable design solution.

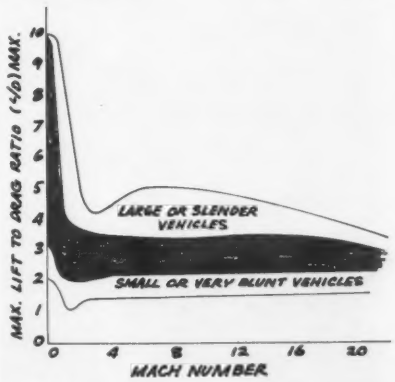
Most future space-system requirements mention re-use and operational flexibility as desirable design goals. This indicates the importance being placed upon low total system costs and a versatility in action allowing command and dispatch of a space vehicle at any time or to any place deemed necessary. Obviously, the latter is extremely important to the military.

The art of lifting-re-entry design must progress rapidly in the area of re-usability to insure sound technical programs; for it offers more promise for satisfying re-use and operational needs than any other recovery technique. Re-use is a difficult characteristic to assess. Besides being a function of re-entry environment and accompanying structural deterioriation, such factors as the flexibility of the airframe, coating type, and panel-flutter characteristics will all contribute to the degree of re-usability

Hypersonic Drag Polars



L/D_{max} Spectrum for Lifting Re-entry



that is inherent in a given airframe.

As a matter of fact, lift re-entry structures would have to be fatigue-tested throughout the re-entry cycle to adequately predict re-use capabilities. Such testing is an integral part of many of the present re-entry-structure component programs; but because of the enormity of structural possibilities, accurate structural-life predictions are well in the future.

The mode of landing will influence re-use too; a fully recoverable vehicle that lands as an airplane is certain to possess more re-use than an impacting vehicle which may be subjected to water or rock damage because the landing is neither controllable nor soft.

Operations of the military require special flexibility in weapons because the precise moment of use cannot be forecast. For this reason, it would be desirable to employ lifting re-entry for space vehicles, so that atmospheric maneuvering can be effected upon re-entry to arrive at a designated point on earth that might be well out of the plane of the vehicle's orbit. Likewise, spacecraft could be dispersed for launching, and would allow use of existing facilities and efficient control over operations.

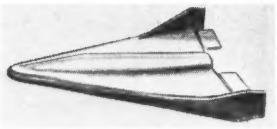
In summary, many applications exist for lifting re-entry, and the U.S. space program is in active pursuit of the inherent potential of the concept. The Air Force–Boeing Dynasoar I project is a case in point. This vehicle is designed to explore a wide flight corridor and offer full-scale experimental proof for aerothermodynamic, structural, and material theories. In addition, this system will serve as the proving ground for certain mission and flight-vehicle equipment as well as a laboratory to study the role of man in the system loop. It is significant that the lifting-re-entry concept has been selected to perform this task.

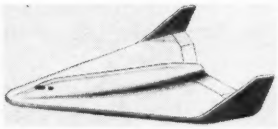
Inasmuch as the major applications for lift re-entry will involve operations much as with manned aircraft, the lift re-entry configuration must combine both desirable hypervelocity aerodynamic characteristics and a suitable mid-velocity and subsonic aerodynamic behavior. These objectives, though often contradictory, are nevertheless capable of being realized. With greater knowledge gained through further analysis and experimentation, optimum solutions should evolve.

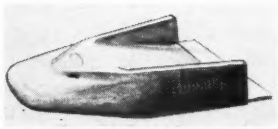
The table on page 76 qualitatively describes desirable aerodynamic characteristics of a lifting re-entry vehicle for each speed regime in which flight will be conducted. Individual mission requirements may place emphasis upon one or another of the parameters listed, but in general the properties listed are those which will produce the best aerodynamic results. Each speed regime has distinctive problems which need customized aerodynamic treatment, hypersonic flight requires special attention to heating, the supersonic and transonic regimes require low drag, and, finally, the landing phase must include good handling qualities and a high maximum lift coefficient.

In the hypersonic speed regime, aerodynamic heating can be constrained if high lift and drag coefficients are simultaneously attained. Large lift coefficient will tend to oppose the descent of the vehicle, thereby promoting (CONTINUED ON PAGE 76)

Advanced Design Profiles for Lifting Re-entry Study

A 

B 

C 

Characteristics	Configurations		
	A	B	C
Structural concept	Thermal-shield hot structure	Thermal-shield hot structure	Composite heat shield cooled structure
Leading edge and heat shield	Coated molybdenum	Coated refractory	Ceramic
Structure material	Rene 41	Rene 41	Stainless steel
Re-entry wt, lb	7600	40,000	35,000
Wing area, sq ft	304	1,143	700
Re-entry W/S, psf	25	35	50
Airframe wt, lb	2830	14,700	14,800
Total contents wt, lb	3166	24,300	19,500
Payload wt, lb	1300	10,000	10,000

Guest speaker at Banquet Night of the Joint National ARS-IAS meeting, Lt. Gen. Howell M. Estes Jr., Deputy Commander for Aerospace Systems of the Air Force Systems Command (AFSC), at the dais, gives his view of "What's Next in Space" to the largest audience ever to crowd the Ambassador Hotel's Coconut Grove ballroom. Seated from left to right at the head table are Charles Ayres and Paul Johnston (not shown), Edward Specht, Joseph A. Walker, Harold Luskin, Gen. James Doolittle, Lt. Gen. Roscoe C. Wilson, H. Guyford Stever, Harold W. Ritchey, Maj. Gen. S. T. Wray, William H. Pickering, Rear Adm. J. P. Monroe, James J. Harford, L. S. Scheinberg, Thomas Dixon, and C. J. Hamlin.

ARS-IAS summer meeting a success

The first joint effort of the two major societies devoted to astronautics and flight science draws 2700 to an interesting meeting on the West Coast

By John Newbauer

MANAGING EDITOR, *Astronautics*

THE FIRST national joint meeting of the American Rocket Society and the Institute of the Aerospace Sciences took place June 13–16 at the Ambassador Hotel in Los Angeles, Calif. This joint meeting registered a total attendance of 2700 members of the space-flight community, which may be compared with the total registered attendance of 2250 at last year's ARS semi-annual meeting held in Los Angeles.

Full Range of Topics Covered

This first joint meeting of the two major national societies devoted to rocketry, astronautics, and flight science offered a full range of activities—technical sessions and panels, luncheons and speakers the first three days, a banquet the third day, a clas-

IAS President H. Guyford Stever, left, and ARS President Harold W. Ritchey both addressed the luncheon Thursday and acted as joint hosts at Banquet Night that evening.

Luncheon speakers Trevor Gardner, left, chairman of the USAF Space Study Committee, and Walter C. Williams, center, NASA Assistant Director for Operations (Space Task Group), discussed "America's Lunar Adventure" and "Operational Goals for Manned Space Flights," respectively. Right, General Estes, who spoke on "What's Next in Space" at Banquet Night.

sified field trip to the Navy's underwater weapon development establishment at NOTS-Pasadena on Friday, and many committee and other business conferences for both societies.

On Banquet Night, Thurday, Lt. Gen. Howell M. Estes Jr., AFSC Deputy Commander for Aerospace Systems, discussed "What's Next in Space" before a record crowd in the Ambassador's Coconut Grove ballroom. Gen. Estes lauded ARS and IAS for their joint effort, said he hoped more joint meetings would be held, and set forth the reasons for a concerted effort by the professional space-flight community.

On technical grounds, he cited the challenges of appropriate booster development, rendezvous and orbital operations with manned space stations, maneuverable spacecraft, and re-entry from deep space with landing control comparable to that for high-speed aircraft. And he suggested that the attainment of these goals demanded more than projects "requiring a boss, a supervisor, to insure a coordinated effort." "More than any other of our citizens," said General Estes, "you must each supply leadership – leadership in educating the public so that the required support of the President's program will be forthcoming; leadership in arguing for higher educational standards, better aligned toward the technical needs of the future; leadership in pressing for imaginative scientific thought and dedicated technical endeavor. Your responsibilities do not permit you to sit back waiting for some other person to inspire you into action."

NASA test pilot Joseph A. Walker, left, receives the IAS's 1961 Octave Chanute Award for "experimental flight testing of and engineering contributions to high-speed flight research programs, including the X-1 through X-15." Dr. Stever makes the presentation.

Professional Goals Noted

The Banquet Night audience also applauded the anecdotes and remarks of joint hosts for the evening, IAS President H. Guyford Stever and ARS President Harold W. Ritchey, both of whom addressed the luncheon the same day, Dr. Stever on "The Promise of the Aerospace Profession" and Dr. Ritchey on "Goals of Our Societies." And they enthusiastically approved the award of the IAS's 1961 Octave Chanute Award to NASA's chief test pilot for the X-15 project, Joseph A. Walker, "for experimental flight testing of and engineering contributions to high-speed flight research programs, including the X-1 through X-15."

At luncheons earlier in the week, Trevor Gardner, chairman of the USAF Space Study Committee, spoke on "America's Lunar Adventure" and NASA's Walter C. Williams, assistant director for operations (Space Task Group), outlined operational goals for manned space flight. William's comments made clear that NASA now has confidence in manned control of spacecraft and will tailor its vehicles to make maximum use of a flight engineer.

If the *Los Angeles Times* newspaper can be taken seriously—and one need not concede that it should —the remarks of the luncheon speakers at the meeting, President Kennedy's recent message on the space program, and three years of other exhorta-

At the Banquet Night reception: Above left, IAS President Dr. Stever chats with ARS Director Samuel Herrick (back to camera) and his lady. Above center, ARS Director Robert Gross, left, explains as how he tied it with a piece of string and it worked to ARS Director Herbert Friedman, center, and ARS Executive Secretary James J. Harford, who look skeptical. Right, *ARS Journal* Editor Martin Summerfield and his lady, left, ARS Vice-President William H. Pickering, and, on the far right, IAS President H. Guyford Stever pause in their discussion for the camera.

tion, reasoned comment, prognostication, and practical demonstration of the meaning and future of astronautics still leaves the majority of our citizens confused, derisive, or fairly indifferent.

Here is what the *Los Angeles Times* said editorially the morning of Thursday, June 15th, the day of the banquet:

"Possibly the biggest reason for public skepticism over the man-on-the-moon project has been the government's failure to pinpoint clearly and forcefully the importance of the scheme. Proponents of space exploration have listed a number of reasons why a man should be sent to the moon. Some are valid, others are silly.

"The best reason for manned space flight is the advancement of scientific knowledge. Yet, perhaps because so few Americans are interested in pure science, this reason has been played down. Instead, there has been a lot of talk about national prestige and military advantages.

"The military benefits of landing a man on the moon, except for the subsidiary ones involved in developing a rocket that will get him there, are still vague and unexplained. The prestige question—beating the Russians and winning a propaganda victory—has some validity. But the controversy over the importance of prestige, with the administration now on one side and now on the other, has left the public more confused than convinced.

"In view of the lack of direction thus far shown by proponents of manned space exploration, public reluctance to back the program is understandable. That reluctance is likely to continue unless some clear answers on the whys and wherefores are forthcoming."

We can hope that the SPACE FLIGHT REPORT TO THE NATION in New York this October will provide the background to (CONTINUED ON PAGE 73)

Edward Specht of GE, vice-chairman of IAS L. A. Section, Maj. Gen. S. T. Wray, Office of Secretary of the Air Force, Gen. James Doolittle, Chairman of the Board of STL, and L. C. Craigie, Lt. Gen. (Ret.) USAF and Vice-President of AMF, talk over recent space events.

Explorer Scouts of the Los Angeles area demonstrate spaceflight simulation equipment they have built in the ARS Youth Education Program.

Technical program announced

More than 50 technical sessions, 250 papers on program . . . Attendance of 15,000 expected . . . Coliseum to house exhibits of 250 companies . . . Special Education Day program planned for final day of the meeting

THE PROGRAM of technical papers for the 1961 ARS SPACE FLIGHT REPORT TO THE NATION, October 9–15 at the N.Y. Coliseum, has been finalized and the printed programs will be mailed August 15, the American Rocket Society announced.

The technical program, which is the largest ever presented, will include a summation of the past year's activities, a close look at the present state of the art, and a preview of the future space-flight program.

Under the direction of George Gerard, Program Committee Chairman, the technical program will feature 53 sessions covering all the astronautical disciplines and approximately 250 papers presented before an estimated 15,000 attendees. The sessions will be held in six specially constructed meeting rooms on the fourth floor of the Coliseum.

The Annual ARS Astronautical Exposition, the largest ever devoted solely to astronautics, will fill the first three floors of the Coliseum with exhibits from over 250 of the nation's leading organizations in the space-flight field.

Technical sessions, held Monday through Friday, October 9–13, have been scheduled so as to present six concurrent sessions each morning and six on Monday and Tuesday afternoons.

On Wednesday, Thursday, and Friday afternoons three special SPACE FLIGHT REPORT panels will be presented on the vehicles, missions, and the global effects of the U.S. space program. The respective chairman of the panels will be Krafft Ehricke, General Dynamics/Astronautics, Arthur Kantrowitz, Avco Corporation, and James Doolittle, Space Technology Laboratories, Inc.

Four concurrent sessions designed for the lay audience as well as the professionals have been scheduled for Monday and Tuesday evenings. A complete review of the U.S. and USSR space programs, expected to be televised nationally, will be presented on Wednesday and Thursday evenings. The Banquet has been sheduled for Friday evening October 13.

Highlighting Monday morning's technical program, October 9, will be a session on nuclear-rocket mission applications, under the chairmanship of Robert Trapp, Douglas Aircraft Co. The session will include papers on major performance increases with solid-core nuclear rockets, nuclear rockets for interplanetary missions and manned lunar missions, and RITA—the Reusable Interplanetary Transport Approach to space travel.

Another morning session covering a critical area of research will be power sources for electric propulsion. The session will include papers on a two-fluid MHD cycle for nuclear-electric power conversion, the design fo electrostatic generators for space operations, and Snap-8, the first electric propulsion power system.

The sessions Monday evening will be highlighted by a panel discussion on electric propulsion with Ernst Stuhlinger, NASA, as chairman. The panel will be composed of John Evvard, NASA; A.T. Forrester, Electro-Optical Systems; Mark L. Ghai, General Electric Co.; Richard Hayes, NASA; G. Robillard, Jet Propulsion Laboratory; Milton Slawsky, USAF Office of Scientific Research; and Robert Supp, WADD.

One of the main sessions Tuesday morning, October 10, will cover human factors and bioastronautics under Chairman Col. John Talbot, Research and Engineering, USAF. Papers delivered at the session will include a review of the current bioastronautics programs, problems in providing earth environment for manned space flight, acceleration, and advanced life-support systems.

A unique session on "Technical Information—the Paper Curtain" will be held on Tuesday evening under the chairmanship of Sheldon Isaacson, The Martin Co. The session will deal with the information and communication problems germane to the astronautics industry and will be highlighted by a talk by Sen. Hubert Humphrey on "The Information Problem—Engineering Efficiency—Some Solutions."

One of the prominent sessions to be held Wednesday morning, October 11, will cover missiles and space vehicles. One of the papers presented will

ARS SPACE FLIGHT REPORT TO THE NATION

OCTOBER 9-15, 1961

Session Outline

	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
MORNING	**Robot Exploration** (Jack Froehlich) **Structures and Materials** (Ernest E. Sechler) **Nuclear Rocket Mission Applications** (Robert Trapp) **Logistics and Operational Problems of Very Large Booster Systems** (Phillip F. Fahey) **Power Sources for Electric Propulsion** (John Evvard) **Astrodynamics** (Samuel Herrick)	**Hypersonic Heat Transfer and Vaporization Ablation** (C. F. Hansen) **Human Factors and Bioastronautics** (Col. John Talbot) **Nuclear Instrumentation** (Andrew M. Koonce) **Power Systems** (Major W. G. Alexander) **Electrothermal and Electromagnetic Thrust Generation** (Mark Ghai) **Missiles and Space Vehicles** (Maxwell Hunter)	**Hypersonics** (William H. Dorrance) **Communication Satellite Future Programs** (Frank Lehan) **Missiles and Space Vehicles** (Carl Kober) **New Liquid Rocket Techniques** (Paul D. Castenholz) **Electric Propulsion Missions** (Capt. Richard Hayes) **Environment of Space** (Joseph Kaplan)	**NASA Program Report** (Milton Rosen) **Space Propulsion and Components** (H. G. Jones) **Instrumentation for Manned Space Flights** (Col. John P. Stapp) **Advanced Guidance Devices** (Charles E. Durham) **Environment of Space** (Sidney Sternberg) **Design of Electric Propulsion Spacecraft** (Geoffrey Robillard)	**Propellant Technology for Space Application** (Gerald Morrell) **Magnetohydrodynamics** (Milton M. Slawsky) **Space Law and Sociology** (Andrew G. Haley) **Propulsion System Selection** (Arch E. Scurlock) **Environment of Space** (Jack Ruina) **Post Injection Guidance Considerations** (Charles E. Durham)	SPACE EDUCATION DAY	FINAL DAY OF EXHIBITS
AFTERNOON	**Structures and Materials** (Ernest E. Sechler) **Propulsion Reactor Op. Problems & Facilities** (Gaylord Newton) **Current State-of-the-Art of Missile and Space Vehicle Flight Testing** (Lt. Col. P. B. Peabody) **Electrostatic Thrust Generation** (A. T. Forrester) **Astrodynamics** (G. Leitmann)	**Human Factors and Bioastronautics** (Brig. Gen. Ted Bedwell, Jr.) **Communication Satellite Current Programs** (William Pickering) **Power Systems** (U. B. Thomas) **Hypersonics** (Walter R. Warren) **Military Program Review** (Col. Harry Evans) **Electric Propulsion Testing** (Robert Supp)	**Space Flight Report Panels** **The Vehicles** (Krafft Ehricke) **The Missions** (Arthur Kantrowitz) **The Global Effects** (James Doolittle)				
EVENING	**The History of Liquid Rockets** (A. J. Kelly) **Electric Propulsion Panel** (Ernst Stuhlinger) **Astrodynamics** (Robert M. L. Baker, Jr.) **Continuing Education** (Vince Haneman)	**Human Factors Panel** (Eugene B. Konecci) **Space Law and Sociology** (Andrew G. Haley) **Power Systems** (G. M. Anderson) **Technical Information: The Paper Curtain** (Sheldon Isaacson)	**USSR Space Program Review**	**US Space Program Review**	**BANQUET**		

Session Chairmen denoted by parentheses ( ).

ask the question: "How Much Space Flight Can We Afford?" Other papers in the session will cover vehicle dynamics, escape systems, and mission management subsystems for advanced manned space missions.

Another highlight of the Wednesday morning sessions will be a group of papers on the recent advances in electric propulsion. Key points to be covered will be the applications of electric propulsion, performance on nuclear-electric propulsion systems, earth satellite missions for electric propulsion, and long-range programs for electric propulsion.

A NASA program report will be an important feature of Thursday morning's program, October 12. The session will include papers on the current progress of Centaur, the role of Project Ranger, a development report on Saturn, and a review of the Mercury-Redstone program.

Another important session in Thursday morning's program will be a review of the latest progress in space propulsion and components. The session will feature technical papers on spherical rocket engines for space-vehicle attitude and velocity control, retrorockets to be used in Project Ranger, operational status of thrust reversers, and solid-rocket liner and insulation materials.

One of the key sessions on Friday morning, October 13, will concern itself with propellant technology for space applications. Papers will be presented on the application of cryogenic propellants, storable propellants for space flight, and solid propellants for space applications.

Another prominent session scheduled for Friday morning covers the problems involved in propulsion-system selection. Arch C. Scurlock will be chairman of the session which will feature papers on the selection of upper-stage propulsion systems, liquid and solid stages for manned lunar-landing vehicles, and the new gel-solid propellant.

The exhibits at the SPACE FLIGHT REPORT will present a display of present and prototype space capsules, spacecraft, satellites, boosters, missiles, and components. At present 76% of the exhibit area has been reserved, covering a total of 60,000 net square feet of floor space. This area is five times as large as the largest exhibit area at any previous ARS Astronautical Exposition.

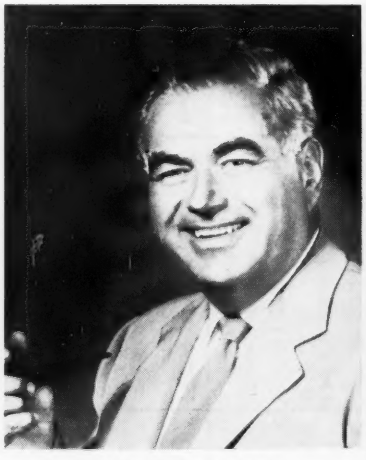
In line with the ARS policy of communicating to the nation at large the value, importance, and significance of the field of astronautics, exhibits at an Annual ARS Astronautical Exposition will be open to the public for the first time. The lay audience will be allowed to view the exhibits from 5 to 10 PM on Monday through Friday, from 10 AM to 10 PM on Saturday, and from 1 to 8 PM on Sunday.

A special program, called Space Education Day, has been scheduled for Saturday, October 14, and will be conducted by noted educators and scientists. The ARS Education Committee under the direction of Maurice Zucrow, Purdue Univ., has planned a full day of sessions for high school and college students on educational preparation for the space sciences and space technologies.

The morning Education Day program will cover the objectives and accomplishments of the U.S. space program and the separate roles of engineering and science in space exploration. In the afternoon five concurrent sessions will be held for students in pre-college, undergraduate, graduate, continuing education, and co-curricular activities. ♦♦

SFRN PANEL CHAIRMEN

Krafft Ehricke



Arthur Kantrowitz

James Doolittle

ARS Space Flight Report to the Nation

OCTOBER 9—15, 1961

Application For Hotel Accommodations

Please fill out this application form completely and mail it to:

Miss Sylvia Peltonen, Secretary
ARS Housing Committee
90 East 42 Street
New York 17, N. Y.

HOTEL	SINGLE	DOUBLE	TWIN BEDS
ABBEY, 151 West 51st St.	8.00- 9.00	10.50-12.50	12.50-14.50
*BARBIZON-PLAZA, 106 Central Pk. So.	13.50-15.50		17.50-21.50
*BARCLAY, 111 East 48th St.	15.50-21.50		23.50-27.50
*BELMONT PLAZA, Lexington Ave. & 49th St.	8.50-16.00	14.00-19.00	16.00-20.00
*BILTMORE, Madison Ave. & 43rd St.	8.00-20.00	15.00-25.00	15.00-25.00
*COMMODORE, Lexington Ave. & 42nd St.	8.50-16.50	14.00-20.50	15.00-23.00
*DIXIE, 250 W. 43rd St.	9.00-12.00	12.00-15.00	13.00-17.00
*EDISON, 228 W. 47th St.	8.00-11.00	13.00-18.00	15.00-21.00
*ESSEX HOUSE, 160 Central Park So.	All Space Reserved		
*GOVERNOR CLINTON, 7th Ave. & 31st St.	10.00-14.00	14.00-20.00	14.00-20.00
*HENRY HUDSON, 353 W. 57th St.	8.00-11.00	12.00-16.00	13.00-18.50
*MANGER VANDERBILT, Park Ave. & 34th St.	8.50-21.00	13.00-21.00	15.50-21.00
*MANHATTAN, 8th Ave. & 44th St.	9.00-14.00	14.00-18.00	15.00-18.50
*MAYFLOWER, Central Pk. W. & 61st St.	12.00-16.00		14.00-17.50
NEW YORKER, 8th Ave. & 34th St.	8.00-14.50	11.50-18.00	15.50-20.00
PARAMOUNT 235 West 46th St.	8.00- 9.00	10.00-12.00	12.00-14.00
PARK LANE, 299 Park Ave.	19.00	24.00	24.00
*PARK-SHERATON, 7th Ave. & 55th St.	11.00-16.00		15.00-20.00
*PIERRE, 2 East 61st St.			24.00-30.00
*PLAZA, 5th Ave. & 59th St.			23.00-30.00
*ROOSEVELT, Madison Ave. & 45th St.	8.50-20.00	13.50-24.00	17.50-25.00
*ST. MORITZ, 50 Central Park So.	13.00-16.00		16.00-20.00
*SAVOY HILTON, 5th Ave. & 58th St.	19.00		23.00
*SHERATON-ATLANTIC, Broadway & 34th St.	9.00-14.00	13.00-17.00	14.00-18.00
*SUMMIT, Lexington & 51st St.	14.00-30.00	16.00-32.00	18.00-34.00
TAFT, 7th Ave. & 50th St.	10.75		17.50
VICTORIA, 7th Ave. & 51st St.	9.00- 9.50	12.50-13.00	14.50-16.00
*WALDORF-ASTORIA, 301 Park Ave.	12.00-20.00	18.00-28.00	18.00-28.00
*WARWICK, 65 West 54th St.	18.00		22.00
*WELLINGTON, 7th Ave. & 55th St.	8.50-12.50	13.00-18.00	13.00-18.00
WOODSTOCK, 127 W. 43rd St.	7.00- 9.00	10.00-14.00	10.00-14.00

Rates subject to 5% New York City tax on hotel rooms. *Suites available. For reservations contact housing bureau.

---------- CUT ALONG THIS LINE ----------

Hotel Accommodations Desired. (It is necessary that five choices of hotels be listed below:)

INDICATE APPROXIMATE RATE AS SHOWN IN SCHEDULE		TYPE OF ROOM DESIRED		
CHOICE	HOTEL	SINGLE 1 PERSON	ONE DOUBLE BED— 2 PERSONS	TWIN BEDS 2 PERSONS
1st				
2nd				
3rd				
4th				
5th				

If accommodations are not available at any of the above hotels, reservations will be made at some other suitable hotel.

NAME.....

AFFILIATION.....

ADDRESS (Home/Bus.).....

CITY..... STATE.....

DATE ARRIVING..... ARRIVAL HOUR..... DATE DEPARTING.....

Please list names, affiliations and desired accommodations for additional persons on separate sheet and attach to this form.

NOTE: There will be an interval of several weeks before you can expect to receive a direct confirmation from the hotel accepting your reservation. Room numbers cannot be assigned by hotels until guests register on arrival.

MAKE YOUR RESERVATION NOW

(CONTINUED FROM PAGE 25)

vehicle could place a 40,000-lb payload in a 300-n.mi orbit. A 5-million-lb gross weight vehicle with liquid hydrogen-liquid oxygen stages above the first solid-propellant stage could deliver a payload of 212,000 lb to a 300-n.mi orbit.

The most important result of these early studies was the conclusion that solid-propellant systems based upon technology existing at that time were competitive with liquid-propellant boosters based upon liquid oxygen and RP fuel. In some situations, where the thrust-to-weight ratio could be optimized, the initial takeoff weight of a given vehicle need be no greater with a solid-propellant booster than it is with the liquid-propellant booster. For such vehicles, the 6–7% lower specific impulse of the solid propellant does not result in greater stage weight because the optimization of thrust-to-weight ratio will appreciably reduce gravity loss; the lower specific impulse has been balanced by the lower gravity loss. This situation is not necessarily true for all space vehicles. Later, we will show that the aerodynamic loading on the vehicle may impose a requirement for the solid-propellant stage to burn for longer times than is optimum for minimizing gravity loss.

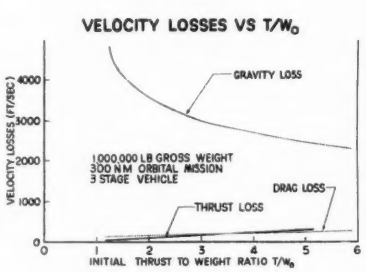
Upon completion of the two initial screening contracts, NASA proceeded to fund programs for more detailed analysis of launch vehicles with solid-propellant stages. These would be designed about the technology described in the earlier studies and in addition would be directed toward optimization in terms of cost for performing the mission. Two specific vehicle classes were considered—a 1-million-lb and a 7-million-lb gross-weight vehicle. These approximately represent the Saturn and the lunar vehicle systems. The payloads of the two classes were 48,000 lb in a 300-n.mi orbit for 1-million-lb vehicle and 125,000 lb to escape velocity for the 7-million-lb gross-weight vehicle. Information on the liquid hydrogen-liquid oxygen upper stages was supplied to the contractors by the NASA Marshall Space Flight Center. Three contractors were supported: Aerojet, Thiokol, and Grand Central Rocket.

The three programs were completed in March 1961. There was good verification of the previous conclusions obtained by Lockheed and Aeronutronic concerning the feasibility of using existing solid-rocket technology for the manufacture of the components of the solid-propellant boosters. Propellant compositions, case structures, vector control systems, insulation materials—all were well established in various military rocket programs. The major areas of unknown technology were those relating to the size and weight of the motors needed for these large vehicles. Hence, the logistics of manufacture, inspection, shipment, and launching received detailed examination. The considerations on logistics reached two sharply different conclusions. One group of contractors concluded that the most attractive and reliable method for making the giant motors required for the space vehicles was to "build" each motor of segments; another group, after examining the same problem, concluded that it was most desirable to make the motor in a single piece.

The virtues of each of these two approaches have been argued at great length within the solid-rocket industry during the past year. Those in favor of segmenting point out that the manufacture of the segment represents a relatively small extension in size over the manufacture of motors such as Minuteman. Essentially all of the casting, curing, inspecting, and shipping methods developed for the Minuteman motor can be used to make the segment of the space motor. It follows, according to the proponents of this method, that one can obtain the reliability of the military solid rocket in the large space rocket. Furthermore, these proponents state, no new facilities are required to make the segments. Only moderate enlargement of existing plants is necessary.

The proponents of the alternate approach contend that the presence of the extra joints in the segmented motor must result in lower motor reliability than would be obtained in a non-segmented motor. The major difficulty faced and accepted by these contractors is the fact that no propellant manufacturing plant in existence can make a motor containing a million pounds of propellant, 15 ft in diam and 70 ft long. Furthermore, very little experience exists in hoisting and moving objects of this weight, and ordinary railroad shipment cannot accommodate these dimensions and weights.

Effect of Thrust-to-Weight Ratio on Losses



The proponent of the unsegmented motor accepted these facts and proposed that the motor be made, inspected, shipped, and handled by new techniques. In essence, the large weight of the motor would be borne for all transportation purposes by water. The motors would be cast in a floodable basin. For static-test purposes, the casting basin would also be the test stand. The motor would fire vertically, without being moved from the cast and cure position. For shipping, a caisson around the motor would be sealed, the basin flooded, and the container floated onto a special partially submersible barge. The barge is brought to normal attitude and towed to the launch facility. Here, the process is reversed. The barge is partially sunk, the caisson towed off and maneuvered to the location of launch pad. Water is removed from the launch basin and the motor caisson is maneuvered into the proper vertical position for launching the vehicle. Once one has accepted this approach to motor manufacture and transport, and provided the facilities, it seems clear that motors of almost unlimited diameter, containing appreciable more propellant, can be made and handled. Thus there is more growth capability in this concept.

The basic controversy between the two camps centers on the question of the reliability of the joints in the segmented motor and on the total reliability of the non-segmented motor. Those who favor segmenting state that reliability is produced by a multitude of inspection, quality insurance, and rejection operations. These operations can be performed on the segments, they state, by well-established methods. The non-segmented, monolithic motor has no background of quality assurance and inspection technology. Thus, while the number of joints is indeed reduced, the unknown state of the materials in the motor must result in degradation of total reliability.

The advocates of segmenting point out that many static firings would be made of single segments prior to the firing of the complete multi-segment motor. This in itself leads to higher confidence level, and in addition gives lower development costs. This capability for static testing with segments has considerable virtue. The size of the motor required for the space launch vehicle is so great that relatively few will be allocated to the static-test program. In all probability, the number of full-scale tests of the motors will be no more than 10 or 12. The firings with single segments, there-

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"Randomness is the only ultimate limitation on precision in such a situation. The magnitude of the random component of physical shift of an image on a plate between exposure and measurement is not great in comparison with the magnitude of the errors in all the other quantities that enter into the computation. Small as the random shift is, it is well that we now have a pretty good idea of its size.

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Our wet friend is now content to work unseen inside a handsome gray box like this, responding to pushbuttons. His very fluidity has been replaced by a kind of viscosity which need little concern the client, who merely inserts a probe into a disposable cartridge. When the work is done, the genie uses his private exit to the sewer.

This newly announced *Eastman Viscomat Processor* does 36 feet of 16 mm film per minute. Not entirely by coincidence, this happens to be the rate at which film runs through a projector. The film spends about one minute in the processor. It emerges processed to standard commercial quality, ready to project. It can be stopped for seconds or days and restarted without loss of quality. Were we not so touchy about processing quality, the gadget would have been on the market long before this. But since we are also film-makers by trade and want to keep our faith in photography, we refuse to be party to sloppiness in film-handling.

For a pamphlet about the Eastman Viscomat Processor, write Eastman Kodak Company, Motion Picture Film Department, Rochester 4, N. Y. A new booklet about where it comes from may prove even more worthwhile. This one is broad in scope, as hinted by the title, "Kodak, a Force in Being." It undertakes an inventory of the capabilities we have exhibited for creative collaboration with other organizations, not only in photography but also in optics, mechanisms, electronics, and infrared. We hope it will strike you as a sober self-appraisal—prejudiced perhaps, but realistic. Request a copy from Eastman Kodak Company, Government Contracts Department, Rochester 4, N. Y.

Kodak
TRADEMARK

This is another advertisement where Eastman Kodak Company probes at random for mutual interests and occasionally a little revenue from those whose work has something to do with science

fore, provide additional opportunity to build up confidence in the components and systems of motors. Those who advocate the unsegmented motor recognize this capability as a virtue. They state that if necessary they could make half-size or quarter-size nonsegmented motors to obtain the same information.

The results of the three study programs containing these considerations are best shown in the illustrations on page 25. Basically, the contractors call for rocket motors 140 to 170 in. in diam, lengths up to 75 ft, thrust per motor up to 3 million lb, with burning times of approximately 60 sec. The motors would contain up to 700,000 lb of propellant. In order to do the large mission, it would be necessary to cluster a number of the motors. Seven motors in a cluster seemed to be the most attractive combination.

By the time the study programs were completed, NASA's requirements for the lunar-landing mission had become more definite. The weight of the spaceship and its manned payload, together with the required on-board propulsion for landing on the moon's surface, takeoff from the moon and landing again on earth, now approaches 160,000 lb. The liquid-propellant motors available for use in the upper two stages of this vehicle, now known as Nova have been fairly well defined. The growth of the payload is reflected in proportionate growth in the solid stage, but, more importantly, the definition of the liquid-propellant upper stages leads now to a more difficult requirement for the initial stages, whether solid or liquid propellant.

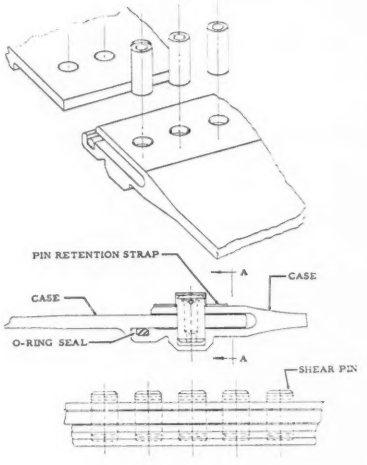
The first stage of propulsion of the vehicle now is called upon to yield an ideal velocity increment in the neighborhood of 10,500 fps. Propulsion engineers know that a single stage to give this velocity increment is quite sensitive to variation of stage mass fraction and delivered specific impulse. The problem for the designer therefore is to produce a stage which retains a sufficient reserve in performance to accommodate the weight penalties that are almost inevitably produced during a development program.

For the solid-propulsion elements, this problem leads to a decision: Two stages of solid propulsion, or one? By splitting the job in half, each part of a two-stage booster can deliver its velocity increment and still retain a very comfortable performance margin. From the pure solid-propulsion viewpoint, two stages for delivering a velocity increment of 10,000 fps is attractive. From the vehicle viewpoint, and from the viewpoint of logistics of handling and launching, the extra stage has many drawbacks. It produces structure and guidance complications, and it certainly requires greater expenditure of development and manufacturing funds.

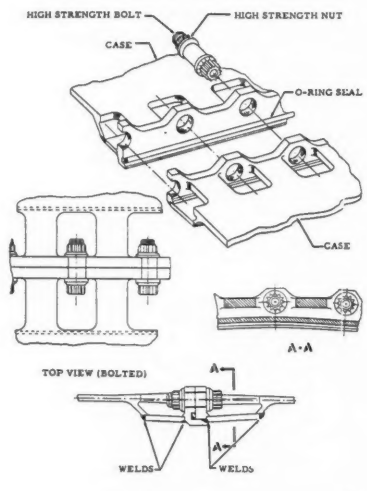
Upon considering all factors, it is concluded that the most desirable solid-propellant element for a lunar vehicle consists of a single stage. The basic element of the stage is a solid-propellant motor containing more than 1 million lb of propellant, about 160 in. in diam and 120 ft in length. Eight of these motors clustered together will form a stage for performing the lunar mission, with a reasonable reserve capacity. The illustrations on page 25 show that the lunar vehicle with this solid-propellant stage is approximately the same height as the all-liquid vehicle. The 160-in. diam is within the size limit of objects that can be moved by most railroads in the country. Therefore, if necessary or desirable, pieces of the motor can be shipped by rail. Needless to say, if rail shipping is adopted, the motor must be made in segments, probably no longer than 20 or 25 ft.

UTC Joint Designs

CLEVIS JOINT



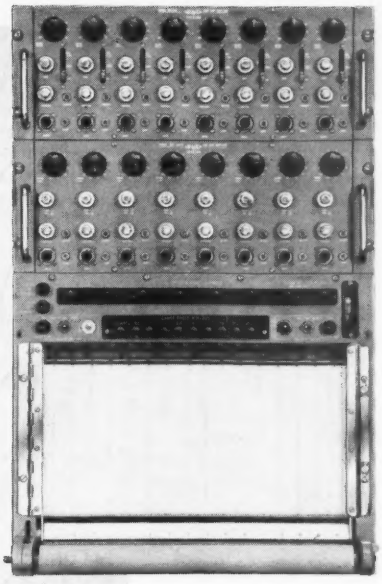
COLINEAR BOLTED-FLANGE DESIGN



I have mentioned earlier that vehicle considerations may impose special conditions on the solid-motor burning time. The major imposition is the requirements that the aerodynamic loading on the vehicle be below about 1200 psf at any time in its flight. This requirement comes from two sources, the first being the structural effects on the relatively fragile liquid-propellant stages. The more important reason, however, is the requirement for the vehicle to be man-rated. This means that the aerodynamic conditions during flight must be such that a rescue or abort maneuver is always possible. The man must have an escape package and must be able to use it. If the aerodynamic loading on the vehicle is too great, the space capsule will be exposed to very high loadings in an abort attempt and the man in the capsule will suffer from extreme g-loads. It is estimated that, even with the maximum loading of 1200 psf, the man in the escape capsule will be momentarily subjected to 16 g's. The burning time and thrust-to-weight ratio of the solid-propellant first stage now must be changed to comply with the maximum Q requirement. In the vehicles that have been studied under the NASA program, this has meant the extension of the burning time of the first stage to 100 or 110 sec for a single-stage of solid propulsion.

This requirement can be met with the propellant compositions and burning rates now available, in reasonable web thicknesses of about 40 in. The major unknown involved in the extended burning time is nozzle heat transfer and the material selection problem. There is considerable optimism in the rocket industry about the ability of proposed nozzle materials to stand up for long burning time, and this optimism is partially supported by the tests that have been made on large motors to date. If jet vanes should be used for vector control, the material problem would be great. However, the most attractive vector control system, and one which will unquestionably receive prime support, is the fluid injection system.

The requirement for a man-safe propulsion system produces another rather interesting problem for solid-propellant stages. It will be necessary to have a warning system to decide when to save the man—in other words, a failure warning system. The liquid-propulsion people have devised fairly complete packages for doing



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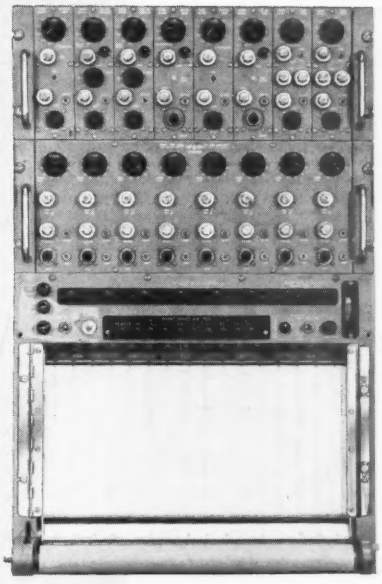

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this. They have systems which sense pressures, flow rates, pump velocities, and numerous other conditions in the liquid-propellant motor, and which give ample warning to the abort package.

For the solid-propellant motor, no such techniques are as yet established. NASA has started programs in this area. It appears that it will be necessary to monitor the pressure in the rocket motors and to determine when an unacceptable pressure or pressure change is occurring. Similarly, the system must detect the onset of overheating and burn-through of the motor case. Both of these modes of failures can probably be detected in sufficient time to actuate the abort package. Needless to say, it will be essential to choose propellant compositions and to devise inspection methods to guarantee with an extremely high assurance level that no detonation-like failure will occur.

You have probably gotten the impression by now that nothing has been done in this program but studies. Not true. Small-scale experimental programs started at almost the same time as the second level of study tasks. The general objectives of the programs were, first, to establish the fact that the manufacture of fairly large rockets or segments of rockets was possible with existing technology and, secondly, to verify designs for segmented rocket motors. Both NASA and AF have supported programs of this nature, each concentrating on different approaches.

NASA first supported a subscale experimental program with United Technology Corp. The purpose here was to demonstrate that reliable and effective joints could be made in solid-rocket motors, and to show that they could be protected during the burning period of the motor. The UTC motor had a diameter of 38 in. and a length of about 46 in. It contained 3000 lb of propellant, with the charge being made in three individual segments. Each segment was inspected and brought to the launch site and there assembled into the complete motor.

UTC examined a great many joint designs for weight and producibility, and finally chose two for testing in the motors. The first of these was a clevis design using radial pins; the other had recessed axial bolts to carry the loads. Three motors were made and fired, two with the clevis joint and one with the bolt joint. All performed perfectly, and post-firing inspection showed that the protective insulation over the joint area had received very mild attack. This was especially gratifying, since the UTC propellant-charge design was a circumferentially slotted cylinder—that is, the propellant charge burned on the surface of the central circular port and in addition on the uninhibited ends of each of the three segments. Thus there was burning propellant immediately adjacent to the insulation over the motor joints. These motors were built according to the UTC concept of the tapered motor. The case and the internal perforation tapered at a half angle of 1.5 deg to maintain essentially constant gas velocity within the central perforation preparation.

The program with United Technology has been extended to a much more impressive scale. The next phase of testing will involve a motor containing about 70,000 lb of propellant, producing 250,000 lb of thrust. It will be basically a scale-up of the smaller motor, with one large central segment and the forward and aft segments. The joint will be of the clevis pin design. This motor should probably be tested by the time this paper is published. The test will also involve a fluid injection vector control system.

Under AF support, Aerojet and Grand Central Rocket have been investigating cylindrical segmented motors. Both companies have examined a great many joint designs and each has made selection of the most attractive one. Aerojet is funded to manufacture two sizes of motors, the first 65 in. and the second 100 in. in diam. A number of firings of the smaller one and one firing of the 100-in. size have been made. All firings have been successful. In these tests, the grain geometry was the normal internal burning star, rather than the radial slotted cylinder design of United Technology. The Aerojet 100-in. motor contained about 100,000 lb of propellant and produced about $^1/_2$ million lb of thrust. The Grand Central task was primarily assessment of joint designs, and therefore they have not loaded and fired any motors. They are proceeding to obtain motor cases hardware 120-in. in diam, once again of the segmented design, and using their tapered pin joint.

You can observe from what has been said up to this point that the major progress in the introduction of solid-propellant stages into space vehicles has been in the area of analytical programs. The amount of experimental work has been limited but it is definitely encouraging. The primary emphasis in the experimental work has been on proving the concepts of the segmented motor and in showing that large segmented motors can be made by the same methods and of the same materials now used for well-established

Boeing Gets NASA Study Contract for Large Solid Rockets

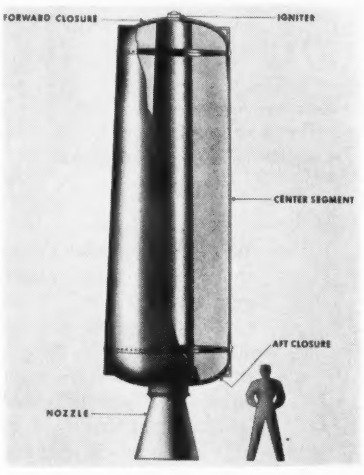
Boeing last month received a $100,000 study contract from NASA's George C. Marshall Space Flight Center to investigate the development of large rockets using solid propellants in one or more stages and liquid propellants in upper stages.

The contract calls for analyses of vehicles in the Saturn-Nova class, capable of placing from 50,000 to 300,000 lb in a 300 n. mi. earth orbit. In this work, Boeing will draw on earlier large solid booster studies conducted by Aerojet, Grand Central Rocket, and Thiokol for NASA.

The six-month study will emphasize the aspects of total launch vehicle systems engineering and overall logistics of space transportation under realistic conditions. Total orbital transportation cost, as well as operation advantages and disadvantages, will be sought. Two families of vehicles will be studied, those with a solid first stage and a high energy-liquid second stage, and those with solid rockets for the first two stages and a liquid-propellant third stage. The liquid upper stages would be powered by lox and liquid hydrogen.

For purposes of the study, the solid units may consist of a large single unit or a cluster of motors, segmented or in a single case. Also included in the study is the possibility of recovering individual spent stages.

Scaled-up UTC Motor Now Under Test



70,000 lb of propellant; 250,000 lb of thrust

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military motors.

I have tried to show that there are a few unusual conditions imposed by the needs of the space launch vehicles. One of these is a requirement for rather long burning time in order to reduce the aerodynamic forces on the vehicle. Another is a requirement for man-rating the solid-rocket motor. The third is size, which calls for some new technology. Here the problem is to show that the reliability of very large solid motors made in segments can be kept at a high level. Alternatively, it will be necessary to prove that as yet unknown problems associated with the manufacture of a monolithic motor can be overcome. Another problem not discussed previously pertains more to the stage than to the motor. We wish to cluster a number of large motors to form the stage. It is clear that the ignition system for this group of motors must be extremely reliable. If one motor fails to receive the ignition signal, the mission will unquestionably be aborted, since the million pounds or more of the unignited motor will be an overwhelming burden for the vehicle.

Still another general area must now be given intensive investigation. The questions relate to the effect of the somewhat higher g-load that results from the thrust-to-weight ratio of the solid stage on the tankage, structure, and interstages of the liquid-propellant stages. Furthermore, close examination must be given to the total vehicle dynamics and to the effect on guidance and control systems for the vehicle. The vibration regime and its effect on liquid-propellant stages, payloads, and instrumentation must be examined. Noise must be assessed.

This sort of detailed study can only be done in the late stages of the vehicle design, when a good idea of the vehicle components has been established. This is the phase now being entered under the NASA program. ♦♦

Big Boosters

(CONTINUED FROM PAGE 27)

efficiencies to them will provide only a marginal superiority over the JP-LOX system, which has mediocre values of ϵ. The application of solid propellants in large boosters should be restricted to the use of high-performance materials whose prices are much less than those currently in production.

These are three broad conclusions for the one mission treated in the graph on page 27—boosting a 300,000-lb payload to 5200 fps. However, the economic comparison made in this graph is valid over the whole range of vehicle operating velocities and payloads, as could be seen from additional similar comparisons, or from a comparison like the one given in the graph on page 27. Here the relative missile cost is plotted as a function of booster burnout velocity for a given fabrication and pricing condition. The graph shows that propellant performance, expressed as specific impulse, becomes an increasingly larger economic factor as the boost velocity of the rocket stage is increased above the low value of 5200 fps used in the first comparisons. Since propellant performance appeared to be the controlling element in that cost picture, the economic advantages of the H_2-LOX combination should be even more pronounced at higher boost velocities.

Some other generalizations may be made from the graph on page 27.

1. The increasing economic importance of propellant performance at high vehicle boost velocities would indicate that the hydrogen-oxygen combination is a better selection for vehicles with few propulsion stages (i.e., with a large boost increment per stage).

2. There is an economic advantage from minimizing the first-stage velocity increment in present systems, using the relatively inefficient JP-LOX combination.

The cost information used in the two graphs presented thus far were obtained from generalized costing charts, such as the two on page 27, which permit a direct computation of vehicle cost for a wide variety of booster missions and propellant specifications. These generalized charts are based on the simultaneous solution of the rocket-motion equation and a cost equation. The motion equation follows:

$$V_{b0} = I_{sp} \cdot g_c \cdot ln \frac{M_0}{M_{b0}} - g_c t$$

where V_{b0} is burnt velocity, I_{sp} is effective propellant specific impulse, M_0 is vehicle gross weight, M_{b0} is burnt weight, and t is propellant burning time. This equation can be expressed in terms of the missile structural factor, ϵ, and the payload factor, λ, so that

$$\frac{V_{b0}}{I_{sp} \cdot g_c} = ln \left[\frac{1}{\epsilon(1-\lambda) + \lambda} \right] - \frac{1 - \lambda - \epsilon(1-\lambda)}{f_0}$$

with f_0 being the initial thrust-to-weight ratio.

Two cost equations are used, one for propellant cost, C_p, and one for structural cost, C_s. Both of these equations may be expressed in terms of the missile payload, M_{p1}, and the specific price factors, K_p and K_s, so that

$$C_p = K_p \cdot M_p = K_p \cdot M_{p1} \left[\frac{1-\lambda}{\lambda} - \frac{\epsilon(1-\lambda)}{\lambda} \right]$$

and

$$C_s = K_s \cdot M_s = K_s \cdot M_{p1} \left[\frac{\epsilon}{\lambda}(1-\lambda) \right]$$

The solution of these equations provides a relationship between the performance ratio, $V_{b0}/I_{sp} \cdot Ig_c$, and the structures cost ratio, $C_s/K_s M_{p1}$, and between the performance ratio and the propellant cost ratio, $C_p/K_p M_{p1}$. These relationships are plotted in the two generalized charts where a fixed value of 1.25 has been assumed for f_0.

To use the costing charts, one must know the values of burnt velocity, propellant specific impulse, rocket structural factor, the payload, and the specific price of the propellant and the structures. All of these items except specific price are mission and propellant specifications, and are readily obtained for any particular application. To obtain the over-all vehicle cost, first compute the rocket performance ratio, $V_{b0}/I_{sp} \cdot g_c$; then use this ratio to obtain corresponding values of the dimensionless cost ratios from the two generalized charts on page 27. Total vehicle cost is then obtained by the following equation:

$$C = M_{p1} \left[K_p \frac{C_p}{M_{p1} + K_p} + K_s \frac{C_s}{M_{p1} + K_s} \right]$$

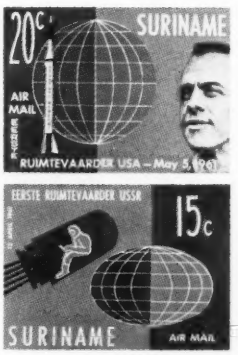
The successful use of the simple specific price factors for structural and propellant costs depends upon the accuracy required in the analysis. These factors are not applicable to a problem in which alternative manufacturing processes or component variations for a particular vehicle are sought. However, in such problems as the economic comparison of propellant combinations, where it is desirable to price vehicles independent of specific fabrication procedures or variations, the use of over-all cost factors would appear to be most satisfactory.

In general, one would expect the use of over-all cost factors to be acceptable in system comparison studies when the cost variations within a system are less than the cost differences between systems. Furthermore, if the analyst is consistent in selecting spe-

cific values of the cost factor for each of the several systems under consideration, presumably any errors in the factors will be in the same direction for all systems. Thus, in analyses where only cost ratios are sought, even relatively large errors in the factors may be tolerated.

The specific price of propellants, of course, is obtained more easily than the structures price, since propellants are sold commercially by weight. The prices of chemicals used in this analysis represent, as far as known, only the manufacturing cost, and do not include distribution cost, allowance for transfer and storage loss, or profit markup. ♦♦

Surinam Stamps Honor Shepard and Gagarin



These new Surinam stamps honoring Astronaut Alan B. Shepard Jr. and Cosmonaut Yuri Gagarin appeared early in July and were immediately sold out at local post offices. The stamps are available from dealers throughout the country.

Grand Central Tests New Solid Propellant

Grand Central Rocket Co. has successfully tested a new solid propellant over what is believed to be the widest temperature range ever achieved, with more than 30 motors containing 50 lb of propellant fired from −100 to +180 F without any kind of failure. The propellant, known as Polycarbutene-R, is made from a production-type liquid polymer of butadiene and acrylic acid, combined with advanced types of curing agents.

Test firings over a wide range of temperatures are continuing with two sub-scale segmented motors, 3 ft in diam, containing over 5000 lb of propellant, and two larger motors with about 8000 lb of propellant.

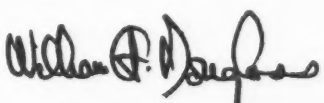
A frank statement about recruitment

Daily changes in defense requirements of necessity affect manpower needs. The national good makes it imperative that critical programs be promptly staffed. Where new jobs cannot be filled from within, and there is no time to train young men, the only recourse is recruitment.

Recruitment is hard, expensive, frustrating work. Worse still, individual employer efforts are often labeled "piracy." And yet the job must be done.

Career Centers, which combine the recruiting efforts of many employers, provide a new approach to these problems. First, the employers may initiate no contact with a man. The man must come to them. Second, a great deal of time and expense is saved for all by having everything under one roof at one time.

Eighty-seven industrial and government employers and more than 10,000 engineers and scientists have participated in Career Centers during the past year in New York City, Los Angeles and Washington, D. C.



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Career Centers are a service of Careers Incorporated, 770 Lexington Avenue, New York 21, N. Y. Publishers of "Career: for the College Man" and "Career: for the Experienced Engineer and Scientist."

ARS news

Gas Dynamics Symposium Set for Northwestern Aug. 23–25

THE FOURTH Biennial Gas Dynamics Symposium, this year devoted to the theme of Magnetohydrodynamics, will be held at the Technological Institute, Northwestern Univ., Evanston, Ill., Aug. 23–25. The 26 papers to be presented at the Symposium will review the science, engineering, and state of the art in the fields of plasma physics, plasma dynamics, magnetofluidmechanics, and associated areas.

The Symposium is co-sponsored by the ARS Magnetohydrodynamics and Electrical Propulsion Technical Committees and Northwestern's Gas Dynamics Laboratory. Ali B. Cambel, head of the laboratory, is General Chairman of the meeting.

Initiated in 1955, the Symposium has as its objective at each biennial meeting the comprehensive treatment of recent research developments in one area of gas dynamics. Problems covered thus cross the boundaries of classical scientific and engineering disciplines, and are problem-oriented. Themes of the three previous symposia have been Aerothermochemistry (1955), Transport Properties in Gases (1957), and Dynamics of Conducting Gases (1959).

Among the features of this year's meeting are a banquet address on Wednesday, Aug. 23, by I. W. Cole, Deal of Northwestern's Medill School of Journalism; a survey report on magnetofluiddynamics and plasma research in NATO Europe by Luigi G. Napolitano of the Univ. of Naples, representing AGARD-NATO; and a panel discussion of MHD power and propulsion.

The panel, first to be held at a Gas Dynamics Symposium, will be kicked off with a review paper on the subject by George W. Sutton of GE's Space Sciences Laboratory, following which current problems and possible solutions in MHD power and propulsion will be discussed by a panel made up of Allen S. Penfold, Litton Industries, moderator; C. S. Janes, Avco-Everett Research Laboratory; Alfred E. Kuhnen, Republic Aviation Plasma Propulsion Laboratory; Stewart Way, Westinghouse; George P. Wood, NASA Langley Research Center; and Dr. Sutton.

The Symposium will be opened by Northwestern's President, J. Roscoe Miller, and ARS President Harold W. Ritchey.

A package price for room, meals, and banquet is available for those who desire to live and eat at the new University dormitories. Reservations should be made prior to Aug. 18, and inquiries on the Symposium should be addressed to: Gas Dynamics Laboratory, Technological Institute, Northwestern Univ., Evanston, Ill.

The program for the meeting follows:

Wednesday, August 23

9:00 a.m.

SOME CLASSICAL FLOWS IN MAGNETOFLUIDMECHANICS

MAGNETOHYDRODYNAMIC CHANNEL FLOW OF A ROTATING FLUID

ANISOTROPICAL PROPERTIES OF MAGNETO-ACOUSTIC WAVE IN A NON-UNIFORM FIELD OF EXPONENTIAL FORM

SURVEY REPORT ON MAGNETOFLUIDDYNAMICS AND PLASMA RESEARCH IN NATO EUROPE

2:00 p.m.

REVIEW OF MOMENT METHODS IN TRANSPORT THEORY

AN APPROXIMATION THEORY FOR CLASSES OF LINEAR BOLTZMANN EQUATIONS WITH APPLICATION TO THE LORENTZ GAS CASE

AN IMPROVED CALCULATION OF GAS PROPERTIES AT HIGH TEMPERATURES: AIR

TRANSPORT PROPERTIES OF HIGH TEMPERATURE GASES

RADIATIVE PROPERTIES OF HYDROGEN AND RADIATIVE TRANSFER TO THE ENVIRONMENT AT ELEVATED TEMPERATURES

Thursday, August 24

9:00 a.m.

EXPERIMENTAL ASPECTS OF MAGNETOHYDRODYNAMICS

EXPERIMENTS ON ALFVEN WAVE PROPAGATION

THE ELECTRICAL PROPERTIES OF IONIZED FLAMES

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HOW ADVANCED IS THE ART OF ENERGY CONVERSION?

Chemical–Electrical: Fuel Cells. The direct conversion of chemical energy to electrical energy via fuel cells has for years been regarded as a great potential power source. The problem has been to translate theory into practical, producible devices. Recent prototype testing indicates this need may now be met.

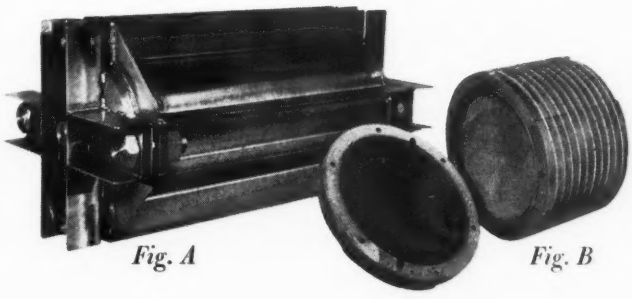

Fig. A *Fig. B*

■—The men at Leesona Moos Laboratories are responsible for a good deal of the early research on fuel cells. Present work is in two main areas: the hydrogen-oxygen Hydrox® cell, and hydrocarbon-air Carbox® cell. Thus far, prototypes of such cells have demonstrated good performance. Outputs with hydrogen equalling 150 watts per sq. ft. of electrode are readily achievable.

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■—*A typical Hydrox® Fuel Cell test battery is shown here. Fig. A shows the complete assembly and Fig. B indicates the internal fuel cell electrodes. It is but one of many configurations designed by Leesona Moos Laboratories.*

■—Leesona Moos Laboratories has been actively involved in the field of energy conversion for 13 years. Thermoelectric, electrochemical, and nuclear power sources, ranging from megawatt reactors to microwatt batteries, have been investigated. Some of these are offered as products, for example, the Dynox® solid state battery, Raypak® nuclear power pack, and Betachron® nuclear timer. An informative brochure on current state of energy conversion techniques with emphasis on fuel cells is available from Department 21.

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On the calendar

1961

Aug. 1–3	4th Western Regional Meeting of American Astronautical Society, Sheraton-Palace Hotel, San Francisco, Calif.
Aug. 7–9	**ARS Guidance, Control, and Navigation Conference, Stanford Univ., Palo Alto, Calif.**
Aug. 14–22	Modern Developments in Heat Transfer special summer course, Univ. of Minnesota, Duluth, Minn.
Aug. 15–17	1961 Cryogenic Engineering Conference, Univ. of Michigan, Ann Arbor, Mich.
Aug. 16–18	**ARS International Hypersonics Conference, MIT, Cambridge, Mass.**
Aug. 23–25	**ARS Biennial Gas Dynamics Symposium, Northwestern Univ., Evanston, Ill.**
Aug. 28–Sept. 1	International Symposium on Rockets and Astronautics sponsored by Japanese Rocket Society, Tokyo.
Aug. 28–Sept. 1	International Heat Transfer Conference, Univ. of Colorado, Boulder, Colo.
Sept. 6–8	IRE National Symposium on Space Electronics and Telemetry, Albuquerque, N.M.
Sept. 7–8	1961 Fall Meeting of Western States Section/The Combustion Institute, Univ. of California, Berkeley, Calif.
Oct. 2–4	Seventh National Communications Symposium of IRE Professional Group on Communications Systems, Municipal Auditorium and Hotel Utica, Utica, N.Y.
Oct. 2–7	**XIIth International Astronautical Congress, Washington, D.C.**
Oct. 4–6	American Society of Photogrammetry Semi-Annual Convention, Biltmore Hotel, New York, N.Y.
Oct. 9–15	**ARS SPACE FLIGHT REPORT TO THE NATION, New York Coliseum, New York, N.Y.**
Nov. 12–17	Conference on Medical and Biological Problems in Space Flight, Nassau, Bahamas.

1962

Jan. 24–26	ASME Thermophysical Properties Symposium, Princeton Univ., Princeton, N.J.

INFLUENCE OF RADIUS RATIO ON MAGNETIC ANNULAR SHOCK TUBE OPERATION

2:00 p.m.

THE COMBINED EFFECT OF TENSOR CONDUCTIVITY AND VISCOSITY ON AN MHD GENERATOR WITH SEGMENTED ELECTRODES

ENERGY TRANSFER TO PLASMAS BY CONTINUOUS LORENTZ FORCES

LOSS MECHANISMS OF A LOW TEMPERATURE PLASMA ACCELERATOR

TRANSIENT BEHAVIOR OF PLANAR ION BEAMS

8:00 p.m.

MAGNETOHYDRODYNAMIC POWER AND PROPULSION

PANEL DISCUSSION ON MHD POWER AND PROPULSION

Friday, August 25

9:00 a.m.

THE STABILITY OF VISCOUS FLOW BETWEEN ROTATING CYLINDERS IN THE PRESENCE OF A STRONG AXIAL MAGNETIC FIELD

THE MAGNETOFLUIDDYNAMICAL VISCOUS COMPRESSIBLE FLOW ABOUT WEDGES AND FLAT PLATES

MAGNETOHYDRODYNAMIC FLOW PAST A FAMILY OF BLUNT AXISYMMETRIC BODIES

THE FLOW OF AN INVISCID COMPRESSIBLE CONDUCTING FLUID PAST A SLENDER BODY OF AN ARBITRARY CROSS SECTION

2:00 p.m.

PLASMA BOUNDARY LAYERS

KINEMATIC FORMULATION OF ROTATIONAL FLOW IN MAGNETOGASDYNAMICS

QUASI-ONE-DIMENSIONAL MAGNETOGASDYNAMIC FLOW

AN EXAMPLE OF HIGHLY RAREFIED PLASMA FLOW ABOUT A THIN AIRFOIL

ARS to Publish Full Charter Senior Member List Next Month

ARS Membership Committee Chairman Abe Zarem has announced that 721 charter Senior Members have been selected by the special committee appointed by the Board of Directors and that their names will be published in next month's issue of *Astronautics*.

1961 ARS Meeting Schedule

Date	Meeting	Location	Abstract Deadline
Aug. 7–9	Guidance, Control, and Navigation Conference	Palo Alto, Calif.	Past
Aug. 16–18	International Hypersonics Conference	Cambridge, Mass.	Past
Aug. 23–25	Biennial Gas Dynamics Symposium	Evanston, Ill.	Past
Oct. 2–7	XIIth International Astronautical Congress	Washington, D.C.	Past
Oct 9–15	ARS SPACE FLIGHT REPORT TO THE NATION	New York, N.Y.	Past

Space Nuclear Conference

(CONTINUED FROM PAGE 33)

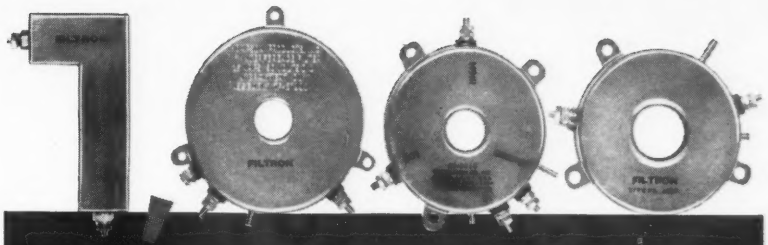
barns range were achieved.

A paper by W. R. Gambill and H. W. Hoffman on "Boiling Liquid-Metal Heat Transfer" summarized theoretical results, which showed great disparity in calculating burnout flux for rubidium and potassium. They proposed a theory which, by simple addition of heat transfer due to convection and boiling, provided results close to the measured values for water. They also suggested the use of swirl flows to provide significant increases in heat transfer, and described some test hardware now being assembled to measure burnout fluxes in the liquid metals.

Another discussion of the possibility of producing "Nuclear Space Power Systems Utilizing Magneto-hydrodynamic Vortices" was presented by W. S. Lewellen and W. R. Grabowsky. This device, which essentially replaces the armature of a conventional homopolar generator by a rotating conducting gas, has been discussed in a number of prior papers. The present paper summarized the thermodynamic performance of the vortex generator with liquid metals as working fluids, but did not consider any of the multitude of engineering design problems attendant on these systems.

The final paper in this session, by A. P. Fraas and J. S. Luce, considered the fascinating problem of "Refueling in Space." A qualitative discussion of the use of nuclear-electric powerplants to "mine" rocket working fluids and propellants from asteroids, moons, and planets, this paper introduced intriguing possibilities such as "sports-car" takeoffs from small asteroids. However, it is obvious that little or no quantitative information on the feasibility of these mining operations is yet available.

A simultaneous session on "Nuclear Systems and Component Research," chaired by W. H. Jordan of ORNL, was offered on the afternoon of May 3. This session consisted of five papers by Oak Ridge personnel and one by Aerojet-General. Four of the ORNL papers, "High-Temperature Corrosion," by E. E. Hoffman, "Fabrication of High-Temperature Heat Exchangers and Radiators," by G. M. Slaughter, "High-Temperature Fuel Element Development," by J. L. Scott, and "Structural Aspects of Reactor and Heat Exchanger Design," by B. L. Greenstreet, were routine discussions of problems encountered some years ago on both direct and indirect-cycle ANP programs. A fifth paper,



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"Pumps for High-Temperature Liquid Systems," by H. W. Savage and A. G. Grindell, described the development of liquid pumps such as those used in the indirect-cycle ANP program, the Molten Salt Reactor, the Sodium Reactor Experiment, etc. The paper was restricted primarily to discussions of mechanical performance (bearings, seals, lubrication, materials, etc.), and included much descriptive material. The final paper was devoted to "Off-Design Operation of a Pump-Fed Nuclear Rocket Propulsion System," by J. H. Beverige and D. F. Vanica.

On the morning of May 4, a single review session on "Nuclear-Electric Propulsion" was held. Despite the extra-heavy load of eight papers, and mostly review papers at that, it was one of the more interesting sessions of the meeting. This was due in great measure to the excellent session chairmanship of David Langmuir, who not only paced the papers with great skill, but also illuminated each paper with a comment or two of remarkable appropriateness.

The review papers on the three general areas of electric propulsion methods, surveys of ion propulsion, by R. Supp, of arcjet propulsion, by G. Heller and B. P. Jones, and of electromagnetic propulsion, by H. Harrison, were all competent and properly complete, with the paper on arcjets being a particularly excellent example of a survey paper. Since this material has, however, been covered in great detail elsewhere, it will not be repeated here. A paper on the "Electric Propulsion Development Program," by E. Stuhlinger, detailed the specific flight-test program, its goals, and its schedule. This ranged from fundamental feasibility tests on arcjet and ion engines using Scout vehicles in 1962 through detailed Centaur vehicle evaluations of all three classes of thrust devices by 1965, as shown in the chart on page 33.

A survey paper by J. W. Stearns titled "Applications for Electric Propulsion Systems" then detailed the specific interplanetary missions most susceptible to accomplishment with electric propulsion. One basic point in establishing the superiority of the electric systems for certain missions was the possibility for subsequent use of the nuclear-electric power supply for experimentation, communication, etc.

The balance of the session consisted of three papers dealing with problems specifically encountered in electrostatic (ion) propulsion systems. "Survey of High-Energy Sputtering Experiments," by D. E. Harrison Jr. and O. C. Yonts, was a compilation of high-energy (1000 to 50,000 v) ion-beam sputtering data, using various working fluids (all common gases) and electrode materials. Although many publications have dealt with the lower range (up to a few hundred volts) characteristic of standard electronic equipment, this apparently is the first exhaustive compilation of data in the high-energy regime. However, a surprising (and total) lack of data on the most interesting alkali-ion propellants (e.g., cesium, rubidium, etc.) severely limits the paper's interest and usefulness to ion rocket applications.

A paper on "Atomic Cross-Sections Review," by W. A. Fite, provided data on ionization and charge-exchange cross-sections of a number of possible propellant materials. The final paper, by E. Fischhoff of Fontenay Laboratories in France, was titled "High-Intensity Ion Source Development," and described a number of sources under development at his laboratories. Among others, a duoplasmatron type and an annular source operating on a magnetron principle appeared to be of some novelty and interest.

The Thursday afternoon sessions (May 4) were on "Radiation Effects and Hazards," chaired by Robert G. English, and "Nuclear Propulsion and Power," with Robert W. Bussard as chairman. The first paper in the "Radiation Effects" session, by W. L. Brown, described "Semiconductor Radiation Damage in Space." The second, "Thin Body Temperature Transients Due to Gamma Heating in Aerospace," by W. Unterberg, demonstrated the computational advantage of the "thin-body" approximation in dealing with the maximum-temperature design problem for certain transient nuclear-energy inputs. Both convective cooling and radiative cooling were considered in the analysis.

The next paper, "Optimizing Reactor Shield, Propellant Boiloff, and Tank Pressure," by R. F. Trapp and J. H. Wilson, considered the problem of radiation heating of the propellant. The authors selected a vehicle geometry, shown on page 33, a reactor leakage level, and a natural uranium plus lithium-hydride shield. They then optimized shield weight against tank weight resulting from pressuriza-

Conference co-chairman C. J. Wang poses with Wernher von Braun at ARS-ORNL Gatlinburg meeting.

Left to right, Brooks Morris, ARS Coordinator of Technical Committees, Robert H. Sehnert of Atomics International, and Mrs. and Mr. Orien Hogan of Rocketdyne at reception.

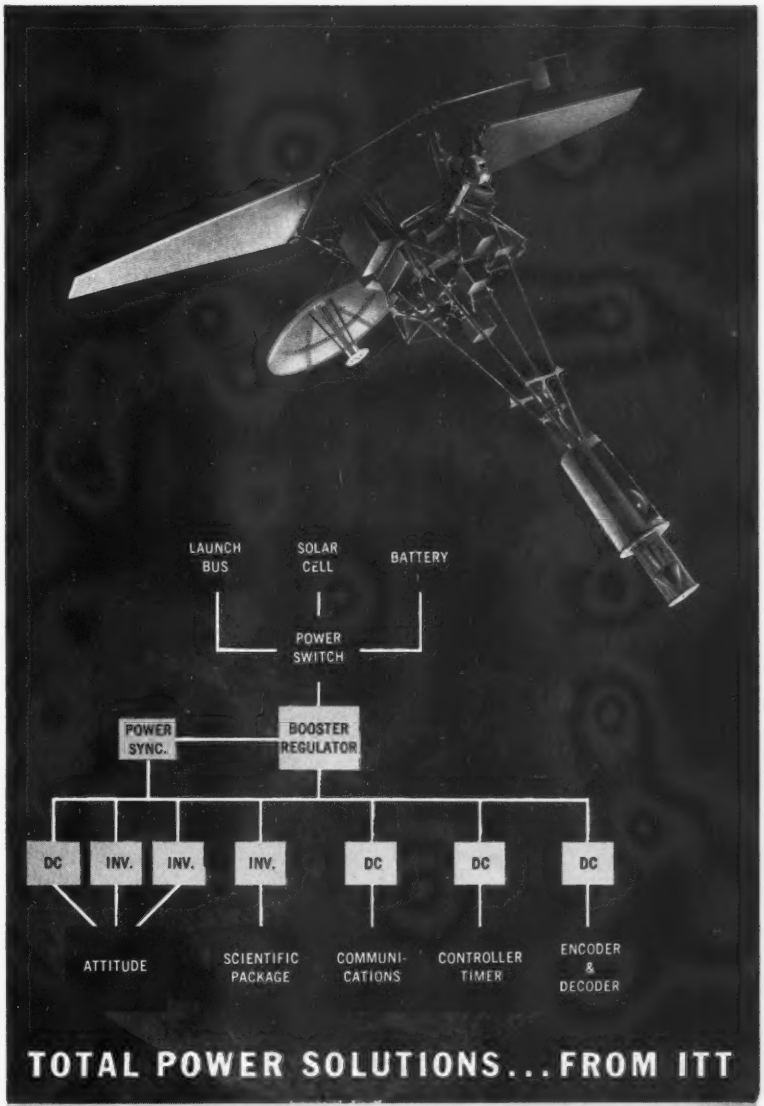
tion due to heating and the weight penalty of venting the hydrogen propellant. The conclusions of the analysis indicated study areas of considerable importance in the serious boiloff design problem.

A paper by Titus C. Evans, "Radiation Hazards of Space Exploration and Radiobiological Principles Involved," surveyed the subject problems. The giant solar flare hazard was found to be the most serious, with the Van Allen radiation belts and galactic cosmic rays both requiring careful consideration. The author concluded on the thought-provoking note that "it will be extremely difficult to insure maximum permissible (radiation) levels such as those we apply to the general population."

P. G. Lafyatis then considered the radiation effects of flight reactors on ground installations and on the general public in his paper, "Hazards Associated with Nuclear Power Reactors in Space Applications." Like Evans, (and also Himmel, et al. as discussed later), who believed reactor radiation effects on crews to be overshadowed by other radiation sources, Lafyatis cautiously gave space the nuclear green light: "High reliability in equipment and techniques will serve to minimize the hazard and can make the use of nuclear power in space applications possible without exposing the general public to any unreasonable risks."

The final paper in this session was "On the Use of Nuclear Rocket Aftercoolants for Booster Recovery," by J. W. Eerkens. The author considered the use of the required reactor aftercoolant flow as "retropellant" for orbit breaking maneuvers, and concluded that these flow rates are too low to provide the necessary levels of retrothrust after typical orbital periods (~90 min).

The second Thursday afternoon session, titled "Nuclear Propulsion and Power," was one of the most interesting of the entire meeting. "The Development and Operational Costs of Nuclear Rocket Vehicles," by W. E. Matheson and R. F. Trapp, was the only "rehash" paper, summarizing data presented in earlier papers (circa 1959). Nuclear engine and vehicle development costs were estimated and compared rather unrealistically with chemical system costs (e.g., recoverable nuclear boosters were compared with nonrecoverable chemical boosters; no shields were included, etc.). The over-all lack of proper data on which to base cost assumptions was reflected in predicted Mars flight costs (based on 100 vehicle reuses!): \$1/lb of payload for 1000-sec I_{sp}, down to 15¢/lb for 5000-sec I_{sp}, with *no* indication of the cost basis (or configura-



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tion) of the as yet undesigned 5000-sec system.

The second paper, "Applications of Low-Power Nuclear Rocket Engines," by R. S. Cooper (see page 34), was in sharp contrast to the first. Discussing the application of carbide or tungsten reactor construction to smaller rocket reactors (e.g., below 2000 mev or 100,000-lb thrust levels, with thrust/weight ratios of the order of 1/10 g), Cooper concluded that significant payload advantages over "conventional" graphite reactors could be realized. Discussion of the paper by Frank Rom indicated that although the carbide reactor looked attractive, water-moderated tungsten reactors in the same epithermal-fast neutron range appear to weigh about half as much. Of course, not all identical assumptions were made in the two analyses, and it is not really clear at this time whether the performance of tungsten reactors would exceed that of the high-temperature carbide systems. However, Cooper's unclassified information on the carbide reactor was one of the highlights of the session and, in fact, of the meeting.

The third paper, by R. H. Fox, dealt with "Realities of Low-Thrust vs. High-Thrust Nuclear Propulsion." Most of the talk was a rather routine discussion of electric power generation problems, but in the last few minutes the author crystallized the low-thrust flight problems of long duration and high gravity losses in a rather interesting light. For electrically-propelled missions departing from low earth orbits, the time to traverse only the *lower* Van Allen belt is 550 hr at a typical acceleration of 10^{-4} g, with the corresponding serious effects of either high radiation dose rates or excessive shielding weight. Combining this with the high gravity loss due to long duration, it appears that either chemical or conventional nuclear heat-exchanger rockets will far outstrip electrical systems for cislunar operations, even without considering the reliability problem attendant to long thrust durations. For planetary missions, even to Jupiter, the gravity loss becomes serious for the low-thrust vehicles. Typical optimum ion systems (10 kg/kw) with 16% payload fraction suffer a gravity loss on planetary missions requiring over three times as much velocity increment as the equivalent zero-gravity maneuver. Under these conditions, the round-trip flight time to Jupiter is over $4\frac{1}{2}$ *years*, with over *three years* of engine operation required. It therefore appears that the reliability problem can become limiting here.

The next paper, by S. C. Himmel, J. F. Dugan Jr., R. W. Luidens, and R. J. Weber, described "Nuclear Rocket Vehicles for Mars and Venus Missions," considering primarily manned flights. The major payload weight then becomes the shield, which, as indicated by Evans earlier, is dictated by radiation from giant solar flares, which occur an average of once every four years. The authors designed a vehicle with a payload vault shield to limit total dose to 100 rem on the assumption of one giant flare occurring. This gave minimum initial vehicle weights for Mars flights of 1.3 million lb and 1.7 million for Venus, assuming takeoff from orbit in both cases with a nuclear rocket having 900 sec I_{sp}. Optimum flight time was around 450 days.

The authors also considered the possibility of gas-core reactors, with I_{sp} of 2000 sec, and showed the interesting result that whereas the specific impulse was the sensitive parameter for Rover-type vehicles (around 1000 sec), the thrust/weight ratio dominated the vehicle weight in the 2000–5000-sec range. The importance of high acceleration (as propounded by Fox in the previous paper) was illustrated by the fact that an I_{sp} of 1000 sec and an F/W of 10 produced a lighter vehicle than one with I_{sp} = 2000 sec and F/W = 0.1. It turned out that by using a gaseous-core rocket, the availability of *both* high specific impulse and high thrust/weight ratios permitted considerable reduction in trip times.

General conclusions were that (a) atmospheric braking on re-entry was very important, (b) shielding assumptions (e.g., number of giant solar flares, etc.) were critical, (c) general characteristics of Mars and Venus vehicles were about the same, with "conventional" reactor rockets ($I_{sp} \sim 900$ sec) taking about 450 days for the trip with 7000–8000 mw power levels. Specific impulse was the most critical single propulsion-system parameter for these vehicles.

Luncheon speaker Harold B. Finger of NASA (left) and W. H. Jordan of ORNL find good news in local paper.

The final paper of the afternoon, by H. L. Reynolds, was devoted to "Pluto." This was a discussion of the whole Pluto concept and of the technical details leading up to the first power run. (This run was made a few days after the meeting and proved highly successful.) The full paper will be found on page 37.

The final day of the conference opened with a session on "Progress of Controlled Fusion Research," chaired by Arthur E. Ruark. As indicated by most of the authors, controlled fusion is an area which is rather academic to the propulsion specialist *at the present time* due to the rather long-range feasibility and subsequent development programs foreseen. However, this will ultimately be a field of major importance.

The substance of the papers, as in previous "briefing sessions" at this conference, was essentially a review of previously published material. The one new subject brought out in the discussion appeared to be the effects of recent empirical discoveries in the field of superconductors. Although the assumption of superconductivity has taken a major role in the "guesswork" formulation of fusion propulsion systems since at least 1955, a significant step by Bell Labs published in April 1961 has indicated the serious possibility of applying this phenomenon to controlled fusion. This was the achievement of magnetic fields of 88,000 gauss (with possibilities indicated up to 200,000 gauss) in superconducting niobium-tin alloys. The attainment of magnetic fields of this order reopens possibilities of practical deuterium-tritium fusion, as well as providing the potential for enormous simplification and cost reduction in any controlled fusion configuration.

Of all the fusion experiments discussed, the one of greatest current interest appeared to be the so-called "mirror machine" described by R. F. Post, in which the reacting plasma is contained by a linear magnetic field cusped at each end by a "mirror." His "Toy Top" experiments indicate no plasma instabilities (the principal difficulty with most geometries), coupled with low diffusion and high electron temperatures.

The papers presented at this session were "Some Aspects of Controlled Fusion Research in the United Kingdom," by R. S. Pease, "The Euratom Controlled Fusion Program," by D. Palumbo, "The Oak Ridge DCX Program," by A. H. Snell, "The Los

Alamos Controlled Fusion Program," by J. L. Tuck, "The LRL Controlled Fusion Program," by R. F. Post, and "The Princeton Program," by M. L. Gottlieb.

The last session, titled "Current Ideas and New Horizons," chaired by Allen F. Donovan, consisted of three papers, "Some Aspects of NASA's Long-Range Thinking," by A. Hyatt, "Mass and Energy Sources in Transformation," by A. H. Flax, and "The Moon, The Meteorites, and the Origin of the Solar System," by H. C. Urey.

Hyatt presented a refreshingly detailed program of NASA's space program, with major milestones outlined as follows:

(1) Suborbital astronaut flight: May 1961 (accomplished the day of Hyatt's talk!)
(2) Orbital astronaut flight: Late 1961
(3) Lunar impact: Mid 1962
(4) Planetary spacecraft: Late 1962
(5) Prototype of active communication satellite: Late 1962
(6) Soft lunar landing: Early 1963
(7) Three-stage Saturn C-1 launch: Late 1963
(8) Orbiting astronomical observatory: Early 1964
(9) Unmanned planetary reconnaissance: Late 1964
(Russians can probably carry out all the foregoing at this time. Could also probably put up equivalent of our Apollo 3-man vehicle now.)
(10) Apollo prototype capsule test: Mid-1965
(11) Three-stage Saturn C-2 launch: Mid-1966
(12) Nuclear rocket flight test: Late 1966
(13) Spacecraft in planetary orbits: Late 1967 (Russians can possibly do this now).
(14) Manned orbital laboratory: 1968–69
(15) Manned circumlunar flight: Mid 1969
(16) Manned lunar landing: Beyond 1970

Hyatt also detailed the various program stages of major task efforts. An interesting conclusion was that a "crash" program might move our 1971-projected lunar landing up to 1969, while a Manhattan-type project *could* move it to 1967, but at enormous cost.

In the second paper, Flax considered some "blue-sky" applications of nuclear propulsion systems, including the use of air as working fluid in first-stage vehicles (similar to nuclear ramjets), as well as planetary atmospheres. He reviewed briefly some of the better-known "advanced" systems,

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e.g., gas-core reactors, pulsed reactors, bomb explosions, MHD, etc., his fundamental emphasis being on the need for upgrading mechanical and electrical systems (e.g., by applying superconductivity to electronic circuitry). The talk ended with a discussion of the possible application of energy from as yet undeveloped principles, e.g., fusion, metastable nuclear states, antimatter, etc.

Dr. Urey closed the meeting with a discussion of the ever-fascinating problem of deducing the origin of our solar system. In studying the solar system, he said, we first became cocksure of our analyses, but after some 10 yr have learned humility. Creation of the solar system was a far more complicated process than it would first appear. Applying this thought to the physical problems of using nuclear energy in space systems appears to be an excellent way of closing this review.

In summary, the Gatlinburg Space-Nuclear meeting covered much old ground, and some new material. As a review of the space field for ORNL personnel, it was excellent, but as a specialists' meeting for those already involved in the space-nuclear program, it left much to be desired in the way of new information. It was thought by some to herald the end of the chemical rocket era; in the opinion of this reviewer, it strongly emphasized the vital continuing (and growing!) role of chemical rockets—particularly boosters—in the coming decade.

Luncheon speakers were Harold B. Finger of NASA (see July *Astronautics*, page 24), Brig Gen. Austin W. Betts (USA), director of the AEC Div. of Military Applications, and Lt. Col. G. M. Anderson of AEC, pinch-hitting for AEC Chairman Glenn Seaborg. Dr. Weinberg was the banquet speaker. Two receptions at the meeting were sponsored by Union Carbide, and two field trips to ORNL were held during the meeting.

The Conference Committee consisted of C. J. Wang of Aerospace Corp., representing ARS, and J. S. Luce of ORNL as co-chairmen; D. D. Cowen of ORNL as local arrangements chairman; A. P. Fraas of ORNL, John Huth of Rand Corp., David B. Langmuir of Thompson Ramo Wooldridge, and Ernst Stuhlinger of the NASA Marshall Space Flight Center.

♦♦

Low-Power Nuclear Rockets

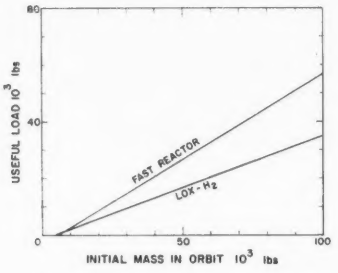
(CONTINUED FROM PAGE 36)

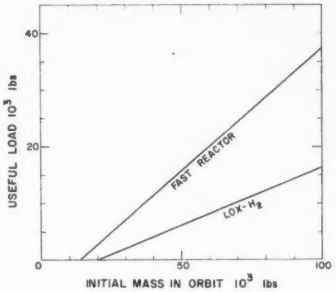
20,000-lb stage, since the reactor weight need not increase much in doubling its power. However, except for the Saturn C-1, which is an interim configuration, there exists no booster with this payload capability, and such a size might not be of lasting interest. The Saturn C-2 has a payload capability of about 50,000 lb, which we shall use as a standard orbital initial mass. Assumptions and typical results are presented in the table and graph on page 36 for a 50,000-lb orbital stage.

Similar results apply to larger stages with greater advantages for the nuclear system, as the engine weight will not increase in proportion and greater I_{sp} can be expected, especially for probes, where only a single reactor run is necessary.

Let us look now at vehicles which carry a payload only one way and return themselves to the starting point (ferries) and vehicles with a fixed payload which occasionally refuel in orbit (satellites).

The ferry will consist of an engine, guidance, and tankage sufficient to hold propellant for the return trip only, and so forth. The initial mass in orbit (M_0) which the ferry picks up will contain a "useful" payload, M_u, propellant, M_p, and tankage, $M_t = fM_p$, for the trip. If m_f is the ferry mass (with no propellant) and R is the mass ratio for a one-way trip, then a simple analysis gives $M_u = [1 - (R-1)f/R]M_0 - (R^2 - 1\ (1+f)/R\ m_f$. We can assume a fixed ferry mass based on a single engine size (e.g., sufficient for orbital masses of up to 100,000 lb) and compute M_u as a function of M_0. We shall give results for two-mission velocity requirements—the first $\Delta V = 12{,}500$ fps each way, corresponding to a 24-hr earth orbit or low lunar orbit, and the second $\Delta V = 20{,}000$ fps each way, corresponding to a lunar landing or Martian orbital supply. Assumptions and results are presented in the table and accompanying graphs on this page.





The results show that the fast-reac- accompanying graphs on this page. stage for both missions and for all orbital masses. Reactor shielding has been neglected here, but might be required for handling the ferry at terminals. We shall show later that relatively small amounts of shielding might be sufficient for fast reactors. Reactors of 2000 mw are sufficient for orbital vehicles up to 400,000-lb gross weight, and in these larger sizes there is relatively little difference in performance between graphite and fast reactors.

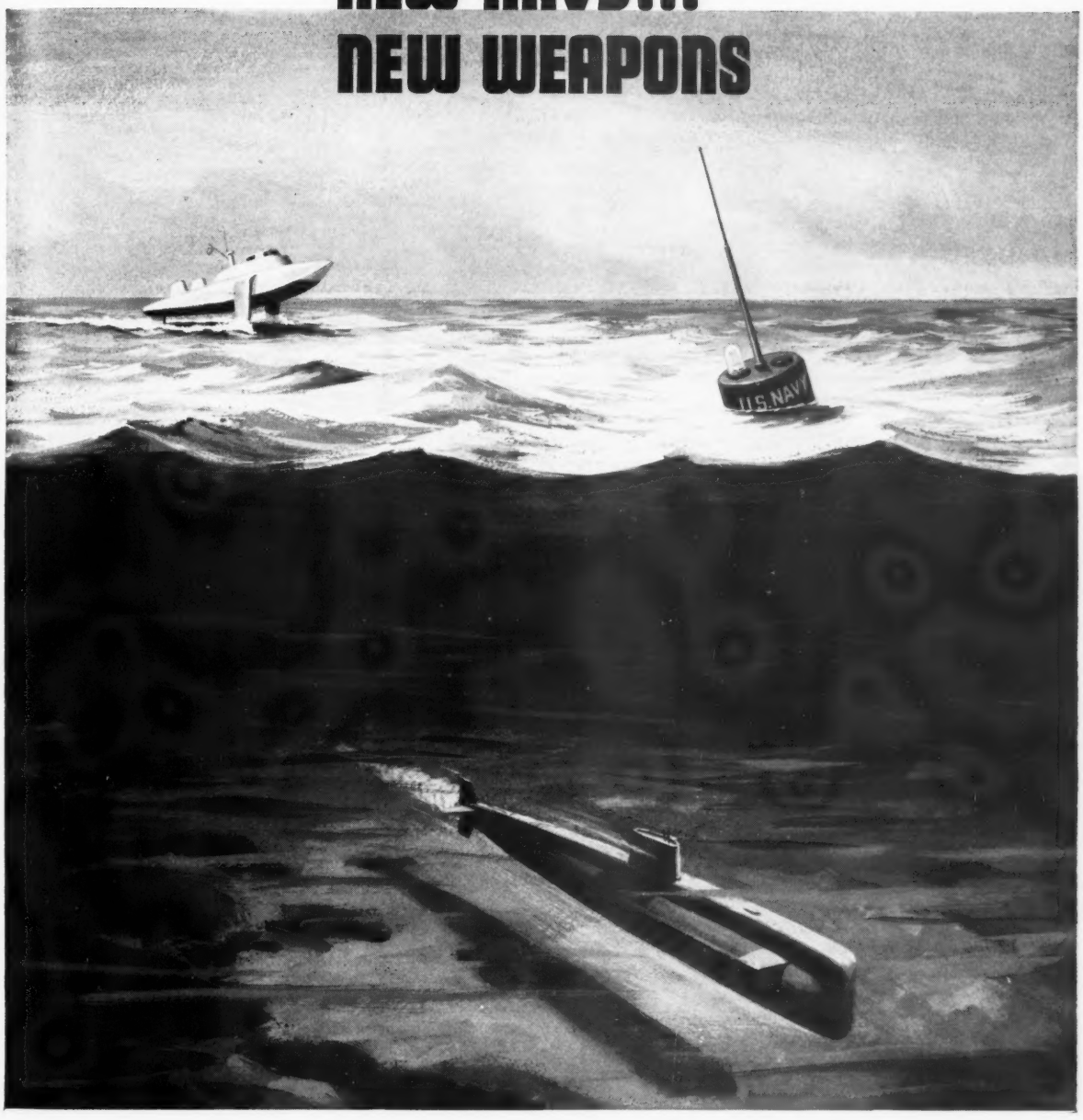
Maneuverable satellites can perform missions similar to those of ferries, but the payload is carried both ways and the emphasis is on manned operations and refuel requirements. Manned operations imply heavier payloads and more advanced systems, so the calculations will be extended in these directions. The payload could be a manned station which travels among various orbits, returning occasionally to a low orbit for refueling and crew exchange, or a supply vehicle carrying a payload and crew to the lunar surface and returning to earth orbit with the crew and lunar soil or ore acting as shielding for the

Performance of Orbital Ferries

The graphs above summarize the data in this table.

System	Lox-H_2	Fast Reactor
I_{sp}, sec	420	860
Ferry weight, lb	1,000	3,500
Thrust, lb	30,000	30,000
Tank fraction (f)	0.03	0.10
M_u (12,500 fps)	0.38 M_0–2200	0.6 M_0–3600
M_u (20,000 fps)	0.204 M_0–4300	0.434–6100

NEW NAVY... NEW WEAPONS



New naval defense concepts are vital in these days of nuclear submarines and guided missiles. One of these: A destroyer-class hydrofoil boat guided to lurking enemy submarines by remote sonobuoys. Ford Instrument is now working to turn this new concept into operational hardware . . . one of the most recent efforts in our 46 years of service to all branches of the armed forces.

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return trip.

As before, we assume a fixed weight for the engine, reactor shielding, etc. for vehicle weights less than 100,000 lb (including propellant), but assume it to be proportional ($M_e = \epsilon M_0$) for larger sizes. The engine, tankage, propellant, and payload will comprise the initial weight in orbit, M_0, and subsequently only propellant and the tankage necessary to contain it (M_{rf}, the "refuel" requirement) will be sent into orbit. This extra tankage can be used for a space station or other purpose after the refueling operation, but will be charged to it. We shall also examine the case where some of the empty tankage is dropped by the satellite during its maneuvers and the refuel tankage replaces it (tank staging). With these assumptions one obtains

$$M_u = M_0\left[\left(\frac{1+f}{R}\right) - f\right] - M_e \qquad M_0 < 100{,}000 \text{ lb}$$

$$= M_0\left[\left(\frac{1+f}{R}\right) - f - \epsilon\right] \qquad M_0 \geq 100{,}000 \text{ lb}$$

where R is the mass ratio for the entire trip. The refuel requirement including tankage is $M_{rf} = (1 - 1/R)(1 + f)M_0$. Vehicle parameters are taken to be those in the table on page 66; but 1000 lb are added to the fast reactor engine (M_e = 2000 lb) for shielding, and an advanced nuclear system (I_{sp} = 1100 sec, M_e + shielding = 8000 lb) is added. The latter case corresponds to a hypothetical nuclear engine with exit gas temperature of about 3200 C and low pressure ($\sim$100 psi) to achieve hydrogen dissociation. The results, given in the table and graph, top right, for ΔV = 25,000 fps again show clear superiority for the nuclear system over the entire range for nuclear propulsion.

The 40,000-fps mission is marginal for chemical single-stage propulsion (payload fraction $\sim$ 0.01), and even for 860-sec nuclear propulsion the payload is about the weight of the tankage. Dropping the empty tankage in n equal steps (equal ΔV's) gives $M_u = M_0[(v + f)/(R1/n) - f]^n - \epsilon M_0$. This has a limit ($n \to \infty$) for continuous tank staging of $M_u = M_0[R^{-(1+f)} - \epsilon]$. Most of the effect is obtained with a single tank staging (n = 2) halfway through the trip. The second table and graph at top right give tank-staging results.

As we have mentioned, the smaller physical size of the fast reactors reduces the masses required for shields of equal attenuation. The shielding requirements will vary greatly, depending upon the application. Relatively little, if any, reactor shielding would be required for most unmanned vehicles, while a 10-in. lead shadow shield (attenuation = 5000) would probably be sufficient for a manned vehicle. If the crew required mobility (as in rendezvous or lunar-landing operations), a thinner shield about the circumference of the reactor would be required to attenuate gamma rays from the fission products, even several days after reactor shutdown. While no significant absolute shield weights can be presented at this time, the table shown below gives some values for representative shields of equal attenuation for three hypothetical reactors, based primarily upon their geometry. These values are presented only to indicate the relative requirements and do not imply that such shields are either necessary or sufficient.

We have not discussed possible disadvantages or limitations of fast reactors applied to rocket engines, as many of these depend upon specific designs or materials. The problem of control of fast reactors has long been in question, but current results with fast power reactors, experimental reactors, critical assemblies, and pulsed assemblies (Godiva II) show that control is generally possible. This leaves fast reactors with the control problems of moderated reactors, plus the complication of a very small temperature coefficient and a smaller mass to absorb the energy of an accidental excursion.

Since the Kiwi-A experiments involved graphite reactors, the fast reactors in a developmental sense are behind graphite reactors. People experienced in reactor development will recognize that concepts are much easier to develop than the materials they require. Furthermore, in this paper we have compared graphite and fast reactors only for low-power engines, and have concluded that for small stages the fast reactors are superior, but that this difference becomes smaller with larger vehicle size.

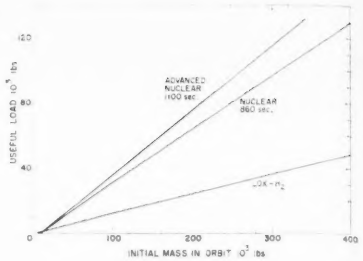
For higher powered engines ($\geq$ 2000 mw), the graphite reactors appear better, since their fissile critical mass goes down very rapidly with size while the fissile mass of fast reactors increases with size. The exact crossover depends upon many factors including detailed design and material capability, restart, I_{sp} achievable, shielding effects, and other factors, and consequently cannot be stated

Maneuverable Satellite Example

Δv = 25,000; payload = 25,000 lb; all weights in lbs.

The graph at right summarizes this table.

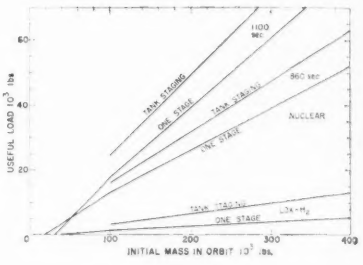
System	Lox-H_2	Nuclear 860 sec	Nuclear 1100 sec
M_0	205,000	80,000	72,000
M_{rf}	178,000	52,000	39,000



Effects of Tank Staging with ΔV = 40,000 Fps

The graph at right summarizes this table.

System	Gross wt/payload None	Single Staging	∞ Staging
Lox-H_2	77	31	27
Nuclear 860 sec	7.7	6.3	5.74
Nuclear 1100 sec	4.7	4.1	4.04



Relative Shielding Requirements

Reactor	Diameter (Be), in. Core	Re-flector	Weight, lb Engine	Lead Shields 10" Shadow	5" Circum.
200-mw UC	10	18	500	1200	2,700
1000-mw UC-ZrC	18	26	2000	2600	5,200
1000-mw Graphite	36	48	5500	9000	16,000

with any confidence now. Nevertheless, graphite appears more favorable for large nuclear rocket engines.

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Guggenheim Propulsion Labs Set Up at Princeton Univ.

A new center at Princeton Univ., called the Daniel and Florence Guggenheim Laboratories for the Aerospace Propulsion Sciences, was established last month. Part of the university's Aeronautical Engineering Dept., the center will be physically located at the James Forrestal Research Center. The new laboratories will cover the fields of jets, rockets, space flight, and aerospace propulsion, and will provide for expanding this area of education and research at Princeton through the construction of a new Guggenheim Laboratories building.

To make the development possible, the Daniel and Florence Guggenheim Foundation has provided a grant of $225,000, payable over five years, of which $25,000 will go for Daniel and Florence Guggenheim Fellowships. Princeton will add about $100,000 to the grant from other funds. Construction of the new building, expected to cost about $300,000, will begin shortly.

The new laboratories are an outgrowth of the Daniel and Florence Guggenheim Jet Propulsion Center, established at Princeton in 1948, one of the first institutions for specialized graduate education and research in this field. The faculty and research facilities of the Jet Propulsion Center now become a part of the new Guggenheim Laboratories.

NSF Issues New Report On Weather Modification

The National Science Foundation has just issued its Second Annual Report, covering Fiscal 1960, on weather modification. The 22-page pamphlet describes NSF-sponsored projects in this area, as well as research programs sponsored by other government and private agencies. It is available from the Government Printing Office for 15 cents.

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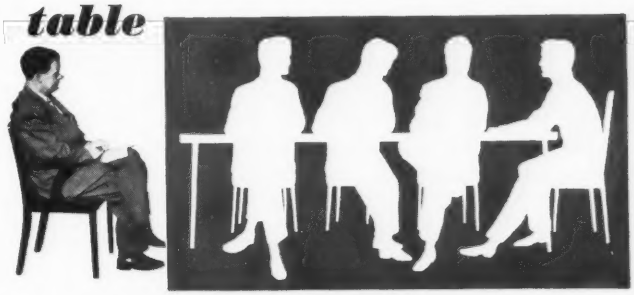

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Air Scooping Vehicle

(CONTINUED FROM PAGE 29)

for a long period of time.

A portion of the scooped gases, preferably nitrogen, would be used for the propulsive fluid to balance this total resultant drag. To do this, the exhaust velocity would have to be larger than the satellite velocity—greater than 26,000 fps. Since only an electrical-propulsion system can accelerate gases to this velocity, a large electric powerplant is required. Moreover, it can be shown that a magnetohydrodynamic (MHD) accelerator is the only practical means of achieving the necessary specific impulse, which must be in the range of 1000 to 1800 sec. The MHD system would accelerate nitrogen by electromagnetic forces through a jet nozzle (see M. Camac's article in the Oct. 1959 *Astronautics*).

While the principles underlying the air-scooping vehicle are straightforward, this by itself does not make the vehicle practical. It must also be demonstrated that there is a feasible design for the vehicle and that it has an economic advantage. This advantage depends on its competitive position with respect to launching liquids from the earth's surface.

In evaluating the economics of the air-scooping vehicle, it is convenient to introduce a parameter we shall call "weight doubling time"—the time it takes to collect and store an amount of liquid oxygen or air equal to the weight of the empty vehicle. This weight is essentially the initial payload weight that must be boosted from the earth into a satellite orbit of, say, approximately 70-mi. altitude.

It can be shown that the air-scooping satellite becomes more economical than multiple conventional boosters if operations are extended over more than approximately two weight-doubling periods—that is, after the weight of the collected and stored liquid oxygen or air reaches about twice the weight of the empty vehicle that is launched into orbit. The weight-doubling time depends mainly on the specific weight (lb/kw) of the electrical powerplant.

The graph on page 29 shows the variation of the weight-doubling time with the power-supply specific weight. The ideal case corresponds to no drag forces other than that due to the scooped gas Thus, operation of this vehicle for several months should result in substantially lower costs than would be incurred by launching liquids from the ground.

The basic design of the air-scooping vehicle is mainly determined from two considerations: (1) the type of energy source used to produce the electric power, needed chiefly for antidrag propulsion, and (2) the external shape that minimizes the total aerodynamic drag for a given scooping rate.

Since the vehicle must operate for a long period of time, it must make use of long-lasting energy sources—solar radiation or nuclear power. Nuclear-reactor systems permit the design of a compact vehicle that can scoop air down to an altitude of approximately 320,000 ft. It is then possible to use conventional air compressors. Notice, however, that the compactness of such a vehicle might require radiation shielding to prevent heating the stored liquid. The sketch on page 29 shows the internal layout of a nuclear-powerd air-scooping vehicle.

Due to the low efficiency of a reactor system, a large fraction of its heat energy must be radiated into space, together with the heat energy of the decelerated scooped gases. To keep the external drag at a reasonable level, the vehicle surface would be used for the heat radiator, at a relatively high temperature. For a given surface temperature the rate of heat radiation from a substantially cylindrical surface is determined by the radius and length of the cylinder. This rate has to be proportional to the scooping rate, which is determined by the inlet radius and the scooping altitude. Vehicles operating at relatively low altitudes will have small cross-sectional areas but will be relatively long. For a fixed scooping rate, the gas-inlet area must be increased as the scooping altitude is increased. On the other hand, the length of the vehicle will decrease with altitude.

Where there is continuous scooping in circular orbits, the dimensions of the internal structure determine, by requiring a certain minimum vehicle radius, the lower limit of the range of possible scooping altitudes. The optimum scooping altitude represents a compromise between the energy requirement of the air compressor and the ratio of external-wall drag to the drag of the scooped air. It lies in the range of 320,000 to 360,000 ft, where "pressure interactions" may critically increase the aerodynamic drag on the side wall. It is absolutely necessary that these interactions be avoided, which is possible if the vehicle surface tapers rearward, as indicated in the sketch of a nuclear-powered vehicle on page 29.

Due to the relatively low flux of solar energy, a solar-powered vehicle requires a converter of considerable size. For this reason it is not practical to scoop in the continuum flow regime with such a vehicle. It must operate in free-molecule flow, which is expected to occur at altitudes of 550,000 ft or higher, depending on the size of the vehicle. Because of the very low free-stream density at such altitude, the solar-powered vehicle must have a very large inlet area if the scooping rate is not to be unrealistically small. However, most of its structure must accommodate only relatively small loads, and hence can be quite light. Since the weight of its other components will be mainly a function of the scooping rate, a solar-powered vehicle will have a relatively large size for its weight.

The low density of the decelerated gases at extreme altitudes poses another problem. Conventional compressors cannot be used because their power requirements would be prohibitively high. Of other methods possible, chemical absorption of oxygen and nitrogen appears promising.

The sketch on page 29 illustrates a vehicle which would use solar power. The vehicle has a rectangular cross section, dictated by the long curtain-like sheet trailing behind the vehicle. This sheet is covered with a direct solar converter, such as solar batteries, which face the sun and produce the required electrical power.

The solar-vehicle's internal structure differs from the nuclear vehicle's. The reactor system and the separator are deleted, and the air-cooling system and conventional compressor are replaced by a chemical collection system. The ratio of the width of the inlet to the length of the converter is fixed by the balance of collected energy to the energy required for air scooping. The height of the inlet (and converter) can be chosen arbitrarily. The frontal area of the solar-powered vehicle will be very much larger and its length (not counting the converter) will be much shorter than that of the nuclear-powered vehicle for the same scooping rate.

Other designs have been investigated but are not as efficient and simple as the two vehicles illustrated. For example, a design having direct feed-through of a portion of the scooped air to the propulsion device is not practical, because of the inefficient operation of the propulsion device under these conditions and complications in the inlet design. Also, operation in an elliptical orbit is inefficient, because the electrical energy must be stored in rather heavy batteries for use during perigee passage.

Because of the relatively large drag experienced by a vehicle in the scooping orbit, it is not possible to perform the transfer of fuel to another space-

craft there. The transfer of liquids would be made at higher altitudes, where the difference in sinking speed due to drag on vehicles with significantly different ballistic parameters would be small. Only a few percent of the stored propellant would be required for such a maneuver. Rendezvous for air-scooping vehicles should be the same as for other spacecraft.

No extensive effort has been made to evaluate an optimized air-scooping vehicle design. Our purpose here has been to show some of the basic relationships which characterize such vehicles and to point to directions which may lead to successful developments. Much work would be required on many of the components. For example, knowledge of the gas dynamics in the region between continuum flow and free-molecule flow is needed for air-inlet design. Liquefaction systems that operate in the "weightless" state require further development. Also, no efficient MHD accelerator has been developed that operates in the specific-impulse range required for the vehicle. However, many of these problems will be solved in connection with the development of other space capabilities, and would substantially reduce the development costs of an air-scooping vehicle.

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UCLA Short Courses Announced

Dates and subjects for engineering short courses to be given by the UCLA Engineering Extension this summer are as follows: Aug. 14–25, "Guidance and Control of Space Vehicles," Nuclear Rocket Propulsion Systems," and "Thermal and Luminous Radiative Transfer"; Aug. 21–Sept. 9, "Experimental Stress Analysis for Missiles and Spacecraft, Photoelasticity and Strain Gages" (in three parts); Sept. 5–15, "Space Communications" and "Thermal Management of Manned and Unmanned Spacecraft"; and Sept. 5–9, "Free-Flight Motion of Symmetric Missiles."

Original painting by Louis Ribak, Taos

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Pluto Program

(CONTINUED FROM PAGE 39)

This concept is called the Tory II-A reactor and operated successfully for 45 sec during a test run recently. The Tory II-A-1 produced 40 thermal megawatts, equivalent to 2000 lb of thrust. Two of these reactors of essentially identical construction will also be tested. The Tory II-C reactor, to be tested after the II-A series, will be a full-scale, missile-like reactor and is intended to demonstrate the feasibility of the Pluto ramjet reactor.

The facility for testing the reactors is at the Nevada Test Site. A map of the facilities appears on page 37. The reactors are tested on unshielded railroad flat cars which can be remotely moved between a test bunker and a disassembly facility. Electrical, air, and water-cooling connections and disconnections to the test bunker can be made remotely. The control room is located approximately two miles from the test bunker. The shielded test bunker contains electronic and air-supply equipment, which must be located close to the reactor. Access to the bunker can be made through a 500-ft-long shielded tunnel while a radioactive reactor is in place. Compressed air at 3600 psi (120,000 lb) is stored in long steel bottles.

During a reactor operation, the air passes into the bunker through a stack of previously heated steel, and then out of the bunker and into the reactor at 350 psi and 1060 F. For the Tory II-A reactor, approximately as much heat is added to the air before it reaches the reactor as is added in the reactor itself. This amount of stored air follows full-power operation of the Tory II-A reactor for approximately two minutes after operation. The air bottles and heater can be recharged in less than two days.

A photo on page 37 shows the Tory II-A test vehicle in place at the bunker face with approximately 700 lb of air per second at 1060 F passing out of the nozzle. The air storage capacity will be increased to approximately 1 million pounds for operation of the Tory II-C reactor.

The main parameters of the Tory II-A reactor are as follows:

Power, Mw	155
Flow rate, lb/sec	708
Maximum fuel-element wall temp, F	2250
Exit gas temp. (tube), F	1975
Core diameter, in.	32
Core length, in.	48
Side reflector thickness (graphite), in.	24

The core contains approximately 100,000 hexagonal fuel elements 4 in. long and 297 mils across flats with 200-mil-diam holes for the passage of air. These tubes are arranged in hexagonal bundles about 5 in. across. The bundles are contained in unfueled BeO structural elements, as shown in the drawing at the top of page 38. The fuel elements are not shown in this figure. An air-cooled Hastelloy R-235 tube is placed in each corner of the hexagonal bundles. The R-235 tubes are attached to a massive front support structure. At the exit end of the reactor the R-235 tubes are attached to coated molybdenum baseplates. The pressure drop through the fueled tubes appears at these baseplates. This load on the baseplates is reacted through the R-235 tubes and appears finally at the front support structure.

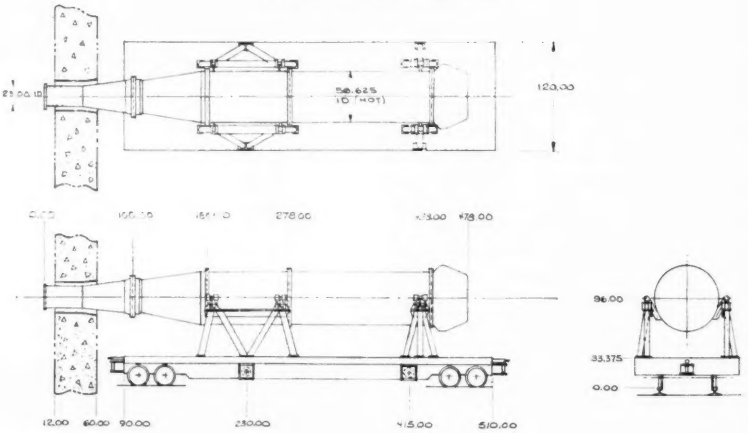
The core is cantilevered from the front support structure by an air-cooled R-235 shroud. The core is separated from the reflector by a water-cooled aluminum pressure shell. The graphite reflector is in two sections which can be separated horizontally so that the aluminum pressure shell can be removed from the reflector. The reflector contains eight graphite cylinders with boron steel at the outer edge of one quadrant of each. These cylinders rotate and control the reactor by increasing or decreasing the effective size of the reflector. Additional fast control is obtained from four linear rods placed near the inner wall of the reflector. All control elements are moved by hydraulic actuators and can be operated singly or in unison. The reflector is watercooled.

Photo on page 38 shows the core during assembly—the BeO structural elements and R-235 tubes can be seen —and the outside of the core. A few of the outside structural elements are in place. The dark tubes are fueled. The painted dots are a code system to indicate the percentage of uranium content. Strain gauges and thermocouples are in place. Other photos on page 39 show the front (upstream end) of the core, where the front-support structure and R-235 tubes can be clearly seen, and the fully assembled core in the pressure vessel.

The Tory II-A reactor was taken critical at Livermore in Nov. 1960. Since a mockup reactor was not available for criticality experiments, the fuel-element loadings were specified from calculation. The calculations were normalized to simple critical configurations having the shape of rectangular parallelepipeds. The calculations overestimated the criticality by about six percent in reactivity. An adequate amount of reactivity was regained by cooling the reflector with D_2O rather than H_2O. The reactor was taken critical at the Nevada Test Site in December 1960. Flow rates without nuclear power of up to 300 lb/sec were also achieved in December. From January to April of this year, efforts were devoted to obtaining completely satisfactory hot piping for the bunker and to improving the reactor's front-support structure and the clamps for the test-vehicle piping.

The Tory II-C design is essentially complete, and fabrication of some parts has begun. A drawing appears here below of the test vehicle and ducting. There will be no water-cooling on the test vehicle. The nozzle and reactor duct will be air-cooled. The reactor will be controlled by linear rods in the hot core. The rods are moved by pneumatic actuators located in front of the reactor in the 1060 F inlet air stream. These actuators together with servo valves and motors have been successfully operated at temperatures of 1200 F for periods of several hours. A facility for the fabrication of the Tory II-C fuel elements has been completed, and their manufacture begun. ♦♦

Tory II-C Test Vehicle



ARS-IAS Summer Meeting

(CONTINUED FROM PAGE 45)

give adequate whys and wherefores.

The open sessions of the Joint Meeting were well attended but fairly low-key. Some 135 papers were presented in the total of 33 sessions, both classified and open. Comments on open sessions follow:

• Electrical Propulsion: Fourteen papers in two sessions largely brought up to date work reported at the ARS Electrical Propulsion Conference of Oct. 1960. Hughes' cesium-ion engine, under development for NASA and scheduled for flight testing in 1962, was reported operating as specified (ARS Preprint No. 61-81-1775). Twenty-six bidders were expected to file last month on a NASA proposal to build a flight-test package. (Awarded to RCA Astro-Electronics Products.) A NASA-Lewis bombardment-source engine will be flown as well as the Hughes motor. Other ion-engine designers are expected to push for flight test through the Air Force. NASA-Lewis gave scaling effects for bombardment source engines (61-87-1781). Avco-RAD gave the first complete systems study in the open literature for an arc-jet (61-101-1795). NASA-Lewis reported regenerative-cooling studies of arcjet engines (61-97-1791). Proponents of colloid engines stalked the halls with fire in their eyes but little hope for support now that the cesium engine has pushed into the little big-time.

• Energy Conversion and Utilization: Good, firm information on advanced power sources and expected performance remain hard to come by. This may hamper planning for ion engines. Four papers in this session turned up nothing new. A well-organized TRW-Tapco Group paper reviewed space power trends in general terms (61-191-1885). The field looks hopefully to the ARS SPACE FLIGHT REPORT TO THE NATION for breaks here. One could come soon on thermionic converters, which have shown surprising efficiencies in experimental versions in the past few months.

• Payload Instrumentation for Space Science: Nine papers in two sessions outlined basic studies for lunar (neutron-gamma bombardment, X-ray analysis, gas chromatography and ultraviolet imaging), ionospheric (Explorer VII and mass spectrometer) and stellar studies (rocket spectrograph and gamma-ray telescope). These sessions produced important papers. In particular, "X-ray Analysis of the

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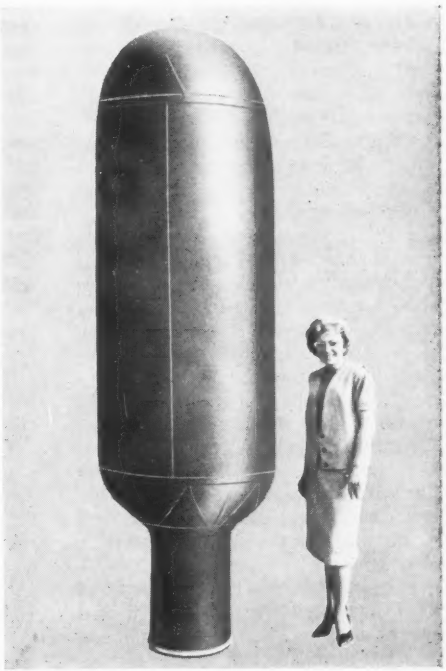

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Lunar Surface" from Philips Electronics (61-109-1803) showed that X-ray analysis is well adapted for space missions, such as comprehensive lunar analysis with the Prospector spacecraft. A JPL paper reviewed measurement of properties of the moon from a soft-landed vehicle (61-11-1805). The paper "Stellar Spectroscopy from Rockets" from NASA-Goddard presented the surprising, if true, finding that emissions fall off much more rapidly from hot stars—to as much as one or two orders of magnitude lower—than predicted by theory. This contradiction will foster some hot work on steller spectra. Thus, the first, crude experiments in rocketborne steller spectroscopy have produced major results.

• Propellants and Combustion: Nothing outside the interest of the specialist reported.

• Astrodynamics: Eight papers were presented in two sessions. An Aerospace Corp. study (61-138-1832) gave the interesting conclusion that two satellites, one high and the other low in drag, placed in an orbit all or partly immersed in the atmosphere will intersect at a predictable place. A GE paper (61-141-1835) described determination of the orbit of a silent satellite by Doppler tracking. Four papers presented rather exact descriptions of thrust pulsing to change orbits. The astrodynamicists are currently tussling over the importance of very exact thrust pulsing to spacecraft maneuvers, in view of errors from other sources in a maneuverable system.

• Space Physiology and Performance: Included in this session of seven papers were reports on the Project Mercury animal program (61-158-1852, sealed-cabin experimentation at AMC-Brooks (61-159-1853), and crew support and restraint studies at NASA-Ames (61-161-1855). It did not appear in this session, but the move is being made to integrate engineering of manned systems. Engineering results will keynote coming reports. For instance, McDonnell Aircraft has compiled the first extensive, systematic experimental data on the reliability of a manned space vehicle, comparing man-modulated and purely machine performance and their interactions.

• Space Operation and Maintenance. This session of five papers reflected the now generally accepted opinion that the astronaut will assume a commanding position in space-vehicle operations. A Martin-Baltimore paper on relating statistical estimates of performance to the maintenance ability of an astronaut showed the new preciseness being brought to this heretofore rather fuzzy area of design (61-147-1841).

• Structures and Materials: Four papers presented—"On the Ultimate Tensile Strength and Elongation of Ductile Materials" by Shanley of UCLA (61-148-1842); "Structural Aspects of Low-Drag Suction Airfoils" from Northrop (61-150-1844); "Leading-Edge Design with Brittle Materials" from Bell Aerosystems (61-151-1845); and "A Unified Engineering Theory of High Stress Level Fatigue" by Valluri of CalTech (61-149-1843).

• Immediate Legal Problems Arising from the Business aspects of Space Conquest: The securing of patent rights and the protection of proprietary interests in work contracted with the government was discussed by industry representatives.

• Deep-space Vehicles: A complete and workmanlike STL report on Pioneer V temperature control (61-178-1872), a description of a GE-MSVD design proposal for a solar probe (61-179-1873) and a JPL design study (61-180-1874) of a Mars-flyby spacecraft with landing capsule comprised this deceptively brief looking session. The solar probe and Mars-spacecraft studies as presented were not definitive, and therefore the papers should be read with care before drawing conclusions about actual flight vehicles from them.

• Communication Systems: Of seven papers in two sessions, five concerned synchronous or high-altitude satellites, active and passive. A TRW Ramo-Wooldridge Div. paper (61-185-1879) on television broadcasting from satellites provided a well-organized view of the potential for TV from a 24-hr orbit. A set of figures for later in the decade would be one channel with 500-kw output and 1000-kw input at about 6.7 lb/kw with shielding; cost estimates vary widely with assumptions concerning launch and reliability. There were also papers on Digilock telemetry for Blue Scout from Space Electronics Corp. (61-197-1891) and communications with lifting re-entry vehicles from Boeing (61-201-1895).

• Space Mission Simulation: Four papers presented. A report by North American Aviation (61-194-1888) on the X-15 flight-simulation program showed the good correlation of pilot-training procedures and actual flight performance. A NASA-Ames paper (61-195-1889) reviewed present work there on simulation of guidance and control in re-entry at super-orbital velocities, with control loops based on Chapman's equation.

There were also open sessions on Air Transport Logistics, Advanced Transports, Operation Support Equipment, Digital Computer Applications in Technical Management, VTOL Systems, Attitude Control (a major subject for the ARS Specialist Conference this month at Palo Alto, Calif.), Aerodynamics, and Underwater Propulsion.

The classified sessions, of course, drew large audiences. The sessions covered the Polaris program (panel), the Titan program, orbital aircraft, advanced air-breathing propulsion, interactions of liquid-rocket engines and vehicles (panel), advanced turbojet systems, and military space systems. This last session was packed to the gills. An experienced engineer leaving it was heard to mutter, "Not with my money!"

The first joint national meeting of ARS and IAS did not ring out the old and ring in the new, but it kept the pace of necessary technical exchange, was reasonably cohesive, and apparently left no one unwittingly out in the cold. The meeting telegraphed an anticipation of big things this fall and winter—particularly the coming SPACE FLIGHT REPORT TO THE NATION to be held in New York in October, a consolidation of plans for advanced manned systems and operations, Centaur flight testing, the first Project Ranger results, buildup to the first Project Mercury orbital flight, Saturn flight testing, and other coming space events with focal power. ♦♦

Nuclear Office for Marshall

NASA's Marshall Space Flight Center has established a Nuclear Vehicles Project Office to manage development of the Rift (reactor-in-flight-test) vehicle which incorporates the Nerva nuclear rocket engine. Col. W. Scott Fellows (USAF) heads the office.

Marshall recently proposed that the Nerva be tested as the second stage of the Saturn C-3 vehicle, utilizing a cluster of two Rocketdyne F-1 1.5-million-lb-thrust engines as a booster. NASA had previously considered testing the Nerva as the second stage of a Saturn S1.

NASA Seeks Reactor Permit

NASA has asked AEC for a construction permit for a second research reactor, to be built at NASA's Plum Brook Ordnance Works near Sandusky, Ohio. A low-power pool-type device and designated the NASA Mock-Up Reactor, it will be substantially similar to the existing Plum Brook Reactor, except that it will operate without forced coolant circulation and at low temperature and pressure.

Careers in astronautics

By Irving Michelson, *Illinois Institute of Technology*

CURRENT lunar exploration programs have had a strong influence on intensified R&D efforts in a variety of specialized scientific and technical disciplines. Such unusual applied scientific byproducts as a refined core-drilling technology have already been noted in this column, and also the additional impetus for intensified solar-energy studies.

More recently, in addition to further broadening of the requisite professional skills, we have been seeing some even more interesting developments. One of these is the advancement of some highly original thoughts about basic concepts for improved lunar vehicles, of the sort that demand serious attention from the most imaginative and able experts in the physical sciences. Another is a growing realization of the importance for purely scientific purposes of the establishment of research stations on the moon. Altogether, the picture is one of blossoming lunar research efforts, and this is certain to have a strong appeal to the diverse interests of the total technical community.

• • •

An important assist for Ranger vehicles is promised by the completion of a new 43-in. telescope which the astronomers will be using for systematic mapping of the lunar surface. A prime objective is to guide decisions of where lunar landings should be attempted. Prof. Z. Kopal of Manchester, England, believes it will also permit the monitoring of operations following landings on the moon, and possibly even locating water beneath the lunar surface. To produce maps of an appropriate scale in the near future sounds like a large order for astronomers, cartographers, and geometricians, and a major assignment for the hydrologists as well.

Gas chromatography on the moon has also moved ahead lately with the development of a special device designed to analyze lunar crust substances in the soft-landing programs. According to designers at Aerojet, it will examine samples from depths up to 10 ft below the surface and relay data back to earth, consuming not more than 10 w of solar power, and is built to withstand impact loads of 100 gs. Over-all design of an instrument which meets these requirements is a task of no mean proportion, considering that it depends in such an essential manner on a variety of distinct modern sub-disciplines. And when it has once performed its function, there will be other questions of data interpretation. No doubt geologists and cosmologists are pondering over what data should be sought, to assure maximum value of benefits received.

• • •

From time to time—sometimes happily just when important new ideas are most needed in space research—our own private Old Space Man Mose comes out of his cave of ivy, utters his few and precious words of wisdom, and retreats heaving his audience immensely impressed and also somewhat dumbfounded. Prof. Fritz Zwicky has done us this service twice lately, first in *ARS Journal* and again in a more recent elaboration of his idea on possible operations on the moon. He offers some tantalizing ideas for application of the solar furnace toward solving the major problems of sustaining life on the moon's surface, using only resources available there. He points out, for example, that in a very efficient solar furnace (notice the hint?), 4000 K temperatures would decompose molten rocks electrolytically, producing the elementary metals as well as gaseous oxygen. Food production through photodissociation of CO_2 in a special chorella algae garden is one of the next steps. We don't doubt that a substantial biological and physical development effort will be required before such dreams come true, and hope that space lessons lately learned have impressed us with the importance of having the boldness to pursue such ideas with great vigor.

• • •

Along somewhat more traditional technological lines, the same sage reminds us of the enormous potentialities of the "bubbly solids" made up of "whiskers" and lamellae of microscopic thickness. The strength of these materials extends orders of magnitude beyond familiar values, and they would be lighter than air if built under high-vacuum conditions or even filled with light gases. The extreme importance of structural weight in all space applications is well known, but we wonder if a large enough segment of materials research is being directed along such lines as these. This will certainly be an important field for researchers in years to come.

Dr. Zwicky also points out the incomparable value of research stations located on the moon. For the astronomer and radio astronomer, the absence of an atmosphere means favorable conditions for observations day and night with no weather effects. In addition, all of the wavelength regions of the electromagnetic spectrum become available for measurement, immensely enhancing the potentiality for analyzing all cosmic phenomena. For example, observation of the Lyman-alpha emission line of hydrogen in the spectra of distant galaxies is not possible from earth, and most costly from rockets. The large-scale structure of the universe would be clarified by the resulting improved knowledge of the nature of the universal red shift.

Moreover, physicists and chemists could operate their equipment in any desired degree of vacuum on the moon, enabling them to produce compounds and materials which can never be produced on the earth. Properties of very pure crystals could be determined there, but perhaps never here, and so on.

The ramifications of lunar research efforts are already most impressive—and the space age is still so young!

For specific career opportunities, see pages 9, 11, 14, 17, 57, 69, 71, 77, and Back Cover.

NSF Fellowships Offered

Applications are now being accepted for NSF Cooperative Graduate Fellowships for the academic year 1962–63 and Summer Fellowships for Graduate Teaching Assistants for the summer of 1962. Applications for the former must be received by participating institutions by Nov. 1 and for the latter by Dec. 8. Additional information and applications may be obtained from the Deans of participating institutions or from the Fellowship Section, Div. of Scientific Personnel and Education, National Science Foundation, Washington 25, D.C.

Precise Measurement Course

George Washington Univ.'s Center for Measurement Science will offer a summer course in the science of precise measurement Aug. 14–25. The Center was established last fall with the support of the National Bureau of Standards and Martin Co. Information on the course may be obtained by writing to the Center, George Washington Univ., Washington, D.C.

Lifting Re-entry Vehicles

(CONTINUED FROM PAGE 42)

maximum heating in the low-density upper atmosphere. Maximum heating rates are therefore less than in flight at low lift coefficient. Nevertheless high lift re-entry will extend the time spent in high-heating flight, so that a large quantity of total heat is absorbed. The net result is that the total heat input predominates, and major attention in lifting re-entry vehicle design must be focused upon a lessening of this effect. The drag coefficient of the body can be a compensating influence by controlling the time of the vehicle in any altitude-velocity condition, so that the total heat transfer is diminished.

The total heat input to a vehicle can be expressed in terms of the ratio of the skin-friction coefficient to total drag coefficient. The composition of the drag coefficient, then, is important in determining total heat input. The high altitudes for maximum heating that are encountered by flight at high lift coefficient imply low Reynolds numbers, which in turn imply higher values of effective skin-friction coefficient. Inasmuch as aerodynamic heating arises chiefly from friction, the laminar skin friction must be suppressed, and the majority of the total resistance should be comprised of form drag as well as drag due to lift.

An examination of the hypersonic drag polar is helpful in studying the desirable mutual relationships between lift and drag. Writing the hypersonic drag polar as $C_D = C_{D_0} + C_L{}^a$, and recalling that for a given lift-to-drag ratio (L/D) it is attractive to achieve the highest possible lift and drag coefficients, we see that high total drag coefficients can be realized at high lift coefficients if we simultaneously combine a large zero lift drag coefficient (mainly form drag), a high lift curve slope, and a high maximum life coefficient. Such a polar is represented as Curve No. 2 on the graph on page 41. Curve No. 1 is the polar of a configuration with zero lift drag, maximum lift coefficient, and lift-curve slope that are less than that of Curve No. 2. Notice that at the required L/D, polar No. 2 can effect flight at lift and drag coefficients substantially higher than can be realized with a No. 1 configuration.

Although a configuration such as polar No. 2 is optimal in hypersonic heating, the drag penalties incurred at speeds below Mach 6.0 may be intolerable. Then, if high values of lift-curve slope and maximum lift coefficient can be combined with a relatively low minimum drag coefficient, the desirable trend can be retained toward simultaneity of high lift and drag.

Once the critical heating region has been traversed, the configuration should be a sharp, slender shape much like the supersonic design of today.

The maximum attainable L/D is the one major item of re-entry vehicle aerodynamic design in this mid-velocity regime which demands special attention. The extent of design compromise toward achievement of a high L/D must he determined by the specific mission requirements and the L/D that the configuration possesses in the hypersonic and subsonic regimes.

The graph on page 41 brackets the L/D_{max} behavior of various lifting re-entry vehicles as a function of Mach number. Because hypersonic heating dictates discrete dimensions for nose and leading-edge radii, the over-all size of a vehicle will determine whether it is aerodynamically blunt or slender. Thus, the boundaries of the graph divide the curve by vehicle size. The upper regions represent the L/D_{max} realizable in large re-entry vehicles, where the stagnation-region radii are small compared to the absolute dimensions of the craft.

Conversely, the lower L/D region is where small, or very blunt, shapes would reside. The shaded area between the two curves represents that gray domain where vehicles are, for instance, either small and slender or large and rather blunted. The curve shows that respectable L/D's ranging from values of 2 to greater than 5 are possible at transonic and supersonic speeds. It is postulated that such L/D levels are adequate for most applications and that it is not necessary to compromise the hypersonic configuration to attain high-L/D supersonic flight.

On the other hand, where requirements set higher over-all L/D_{max}, the aerodynamicist has a problem. If the dictates of the table on page 76 for hypersonic design are followed literally for providing high-zero lift-drag coefficients, then the problem is serious, because the blunt configuration cannot render truly high lift-drag ratios in supersonic flight.

A glance at possible subsonic characteristics of lift-re-entry vehicles is encouraging. It is conceivable that most of the wanted features of the table can be obtained without undue compromise of hypersonic-vehicle design. Acceptable L/D will be realized with all but the bluntest of vehicles, through the attainment of low drag due-to-lift, as the direct consequence of suction at the blunt leading edges of all surfaces. As in the case of the supersonic flight of a lift re-entry vehicle, high zero-lift drag configurations create a block to the development of truly high values of L/D. Once again, however, the importance of this factor must be evaluated against mission necessities, because it is never immediately obvious that very high L/D is required. The moderate subsonic L/D levels between 2 and 6 that are achievable with semi-blunt shapes may be adequate for most lifting re-entry.

Stubby shapes with large base areas will give L/D's in the category of 1.0 at slow speeds. This is considerably less than the generally accepted minimum for conventional landing ($L/D = 2.5$). Therefore, the blunt-nosed vehicle must be made to possess low base drag by some means. Various approaches have been tried involving tapered afterbodies with and without variable geometry.

Variable-geometry configurations recur again and again in lifting-re-entry-vehicle design proposals. The idea, of course, is to achieve the optimum aerodynamic characteristics of each velocity regime without compromise to the aerodynamics in any one regime. The mechanical complications limit this concept, and it is highly desirable to acquire good over-all aerodynamics without such sophistication.

Although it would appear that the nature of the aerodynamics and heating of lifting re-entry from earth orbits is reasonably well understood, the special case of superorbital re-entry is in quite another category. A. J. Eggers of the NASA Ames Research Center, in his recent paper before the ARS Lifting Re-entry Vehicles Conference, stated that phenomena in this speed regime are not yet adequately understood. Of major concern is the nonequilibrium radiation heating from the hot-gas region between

DESIRABLE AERODYNAMICS FOR LIFTING RE-ENTRY VEHICLES

Speed Regime	Lift-to-Drag Ratio (L/D)	Flight Lift Coefficient (C_L)	Lift Curve Slope ($C_{L\alpha}$)	Aerodynamic Center
Hypersonic	—	High	High	
Supersonic	High	Low	High	As nearly
Transonic	High	Low	High	constant
Subsonic	High	Low	High	as possible
Landing	High	High	High	

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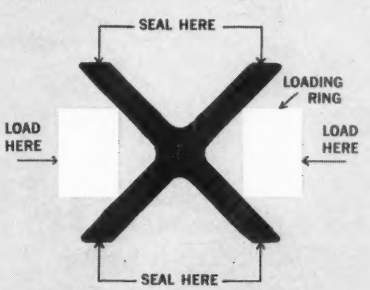

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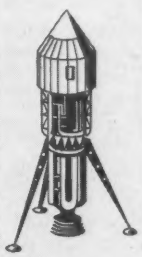
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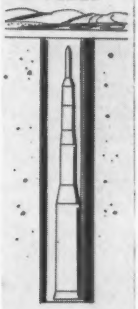
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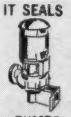
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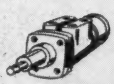
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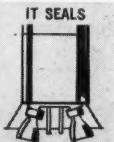
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Therefore, the task of the aerodynamicist is incomplete, but the challenge is clearly defined: conjoin the aerodynamics of every speed regime in such a way that optimum over-all characteristics are obtained. How well and to what extent hypersonic configuration requirements can be integrated with desirable mid-velocity and low-speed characteristics will be the subject of analytical and wind-tunnel studies for some time to come. The scope of the job appears to warrant a full-scale systematic approach to configuration layout that parallels the classic NACA airfoil investigations.

As a matter of fact, NASA is engaged in a substantial effort along these lines which gives selected configurations the full test treatment—subsonic through hypersonic speeds. The program has included mass testing of a variety of configurations at once under one set of objectives and ground rules. This is the type of effort that is sorely needed if we are to evolve fully lifting re-entry.

Besides the work of NASA, the Air Force is sponsoring programs which attempt to provide some quick answers with which to add aerodynamic realism to the many space-system studies being conducted throughout the land for Air Force consumption—realism that must be established now if we are to intelligently assess our futuristic programs.

There is an urgency about this that permeates the industry and government as a whole, and we are learning quickly. However, as each design is lofted on the basis of previous aerodynamic data, it must be carefully scrutinized and put to test to learn if the sum of the parts make up the whole in the manner predicted. There just is not enough general information available to allow assurance that the combining of various components will yield a given aerodynamic behavior. This capability, of course, takes much time and experience to develop.

The real substance of the lifting re-entry vehicle is its physique, the structure. The structure of the life re-entry device must conjoin three arts: a satisfactory use of materials to accommodate thermal and force loads, attainment of the lowest possible weight, and the facility to fabricate. These factors are combined by the structural engineer in three principal ways—by thermally shielded hot-structure, uncooled thick-skinned hot structure, or cooled structure.

The thermally shielded structure, separates to various degrees the load-bearing and heat-control functions. A radiation heat shield re-radiates heat from the surface of the re-entry vehicle to control convective-heating input, including conduction from the hottest to comparatively cool structure.

There are many means for thermal shielding. Insulation is always involved to increase the differential temperature between the skin and structure. How much insulation is employed will depend upon the amount and type of structure. There is invariably a trade-off between the two which will result in minimum weight. We hesitate to speak of low structural weight, because this has no meaning without reference to insulation and heat-shield weights as well.

The thermal-shield approach results in the load-bearing structure being fabricated from materials such as 18-8 stainless steel, titanium, or Inconel X, depending upon the temperature which the insulation allows the structure to experience. The yield-strength-to-weight ratio of materials steadily declines as structural temperature increases, and at a structural temperature of 1500 F this ratio is approximately one-half of the value at 800 F. Therefore, structural weight increases markedly at temperatures above 1500 F.

It so happens that the unit weight of presently available or foreseen insulations is such that the combined weight of structure and necessary insulation also increases as the structural temperature rises above 1000 F. The important factor to be considered in insulation selection is total heat input, and so design of high-lift re-entry vehicles is particularly affected.

Ideal insulation materials possessing good strength, low density, and low conductivity would reduce combined structure and insulation weights. However, strength and elevated temperature resistance are synonymous with high density and conductivity. Therefore, research and development in search of insulations of given conductivity with improved strength at high temperatures is desirable for lifting re-entry applications. The Air Force has supported work in this vein by Avco and Johns-Manville Products. Bringing two such groups together—one design and the other insulation—produces good results. Clear, detailed statements of vehicle-insulation requirements are necessary before the many possibilities known to insulation manufacturers can be adequately brought to bear.

The extreme external skin temperature which radiation heat shield, leading edges, and nose pieces must withstand ranks as the number one materials headache. Thermally shielded structures relieve the outer skin of major load carriage, but the common airframe-construction materials of today falter at re-entry temperatures. Thus, the radiation-cooled structure and the heat-accepting refractory metals have become brothers under the skin.

The materials most often mentioned are molybdenum, columbium, tantalum, and tungsten. It is the molybdenum- and columbian-base alloys that have received the preponderance of attention in the past few years, mainly because general interest seems to have focused on re-entry temperatures in the 2000- to 3000-F category.

This interest continues today with programs such as the one summarized in the table below.

Programs of this type will provide the necessary push that the refractory metals require for application to lift re-entry vehicles. One big obstacle confronting the successful use of these metals is that old disease—oxidation. Without a doubt, oxidation resistance will receive the lion's share of attention in the near future with respect to refractory metals.

At the present time, metals with high strength at high temperature have very poor resistance to oxidation at elevated temperatures. Molybdenum is especially weak in this respect, but the rate at which the other promising metals oxidize is not tolerable either.

As a result, the materials industry is most active in the field of coatings for the refractory metals and has come up with a promising prospect in the so-called pack-cementation process. This process involves mutual action between a molybdenum skin and some silicon which has been diffused into the skin surface. The layer so formed converts to an oxidizing-resistant silica when temperatures above 2000 F are encountered and is useful to tempera-

MOLYBDENUM AND COLUMBIUM DEVELOPMENTS

Program	Purpose	Conducted by	Sponsor
Panel fabrication and static testing	To develop quality sheet material, joining techniques, fabrication methods, and coatings	G.E. and McDonnell Aircraft	ASD Matl's Central and Flight Dynamics Laboratory
In-Fab process, Ti-Mo sheets	To investigate factors influencing fabrication and degradation of materials	Universal-Cyclops	DOD monitored by USN

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Douglas Aircraft Company is part of the Army Ordnance-industry team developing the Nike Zeus Anti-missile System. Western Electric Company is the industrial prime contractor.

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tures slightly above 3000 F. On the other side of the ledger, pack-cementation research has been rather haphazardly treated up to the present time, and consequently the process has emerged without a clear understanding of its nature. Now programs have been initiated to organize and gain insight into the definition, effects, and control of the process variables as well as new process development methods and the performance of the diffusion coatings.

Coatings for refractories must meet some very demanding requirements in addition to protecting the heat shield. Briefly, they must perform adequately and be durable in an environment including noise and flexing not generally conducive to reliability. Consequently, the designer wishes to minimize airframe-induced effects by providing a rigid structure. A conflict emerges, because the rigid structure must be compact, and the compact vehicle will of necessity be of rather high wing loading; but the highly loaded device traverses a re-entry path of least time and cannot advantageously employ a radiating structure. Conversely, the type of vehicle that could make best use of radiation cooling is a vehicle with considerable radiation surface area, which in turn is most difficult to make effectively rigid.

Lift-re-entry configurations that combine high drag and relatively low wing loading will operate at skin temperatures somewhat higher than 3000 F. Here a thermal shield incorporating tungsten shows promise on a strength-to-weight basis. The alloys of tungsten are in their infancy, but there is promise that the future will prove their worth if enough properly oriented research can be directed that way. Again, the problem of excessive oxidation is the major drawback to the utilization of tungsten alloys, just as for other refractories, and so again coatings research needs emphasis.

A clever variation on the theme of radiation-cooled structures is the expandable re-entry structure. Most of the know-how for this technique resides with Goodyear Aircraft and NASA. The concept offers advantages such as compact packaging for placement on the nose of a booster and fewer demands on materials, because extremely low wing loadings can be achieved. Materials such as Rene 41 and Inconel X are usable, and it has been prophesied that in the future metals such as Udimet 700 will receive consideration. The development of suitable flexible oxidation-resistant coatings for the metals is of paramount importance to the success of the concept, and there is activity at Goodyear on these. Such work is a useful addition to coatings research for large rigid structures. Generally, gases prop inflatable structures, but rigid and nonrigid foams are under consideration too.

At low flight equilibrium temperatures a more direct approach to hot-structure design can be used which involves uncooled thick skins. In the lifting-re-entry thermal environment (well above 800 F), however, the concept cannot compete in weight with either thermal shields or cooled structures. It is doubtful that such an approach has much of a future with materials that can presently be reliably forecast, because the tendency in lift re-entry is toward a more severe temperature environment over the entire vehicle.

The concept is simple; skin thickness is increased to compensate for degraded strength of materials at high temperatures. Application of the refractory metals to this concept shares the same problems of thermally shielded structures, plus the fact that the thick outer skin must bear the burden of both force and thermal loads. With further development in the field of certain composite materials (laminates, reinforced plastics, and ceramics), the thick-skinned configuration might warrant further study. Activity in these areas is too limited at the present time to predict success or failure.

The third lift-re-entry concept is the cooled structure. Although there are many means for cooling a re-entry structure, we generally think of them as either internally or externally cooled. There is an option to cool actively by means of jackets or tubes directly adjacent to the primary structure or to provide for the necessary temperature drop by transpiration or ablation.

Cooling allows a conventional structure of aluminum. There are obvious advantages to this, not the least of which is the simplified manufacturing processes that can be used to mass-produce vehicles. The internally cooled cold structure can of course assume many forms, but a promising technique for high-lift devices weds a heat shield of the type postulated for thermally shielded structures to a water-pipe-covered primary structure. A layer of insulation goes between the thermal shield and the cooling tubes to prevent an oversized cooling system. The radiation heat shield will re-radiate most of the heat transferred from the boundary layer, but upwards of 5% of the heat will find its way to the load-carrying structure. The cooling system must maintain this structure at temperatures between 200 and 300 F.

Other schemes for internal cooling involve water wicking and liquefying metal systems.

Without a doubt, very high speed lift re-entry (superorbital) will create increased interest in cooling concepts. Of the present work in this area, the eight-year activity at Bell Aerosystems Co. is an outstanding example. At Bell, the development program includes design and testing of internally cooled structures. This program has demonstrated a capability for maintaining sufficiently low structural temperatures at a variety of representative re-entry conditions. In addition, tests show the feasibility of cooling-system operation at moderate pressures and a mutual compatibility of design for serviceability and manufacturing.

At high equilibrium temperatures, transpiration cooling can be an effective process. A vapor or gas is forced through skin pores to cool the skin and reduce convective heating. Because there is virtually no heat-flux limitation in such a system, truly high-temperature re-entry can be withstood. The weight of necessary mechanical and plumbing components becomes rather incidental, inasmuch as material-property limits are largely eliminated. Work in this field has not received much attention in recent years, although it was under intense study in the early stages of ballistic re-entry development, as internal cooling can be shown to be superior on a weight basis for most applications in the very high temperature range. It would be interesting to see a revival of interest in the technique involving close integration with environment control of the vehicle's internal subsystem.

Cooling by ablation was one of the earliest techniques investigated in re-entry heating studies. Lifting re-entry at superorbital velocities has fostered renewed emphasis by the industry in this means of combating the effects of aerodynamic heating. Schemes are proposed in which organic plastics char at the heated surface, thus cooling by ablation and by back-radiation and gaseous blockage of convective heat transfer. The future of ablating materials in very high velocity lifting re-entry vehicles looks good indeed.

Hybrids of these various structural methods can be considered to constitute yet another breed of design concepts. For instance, a reinforced ceramic composite might serve as the heat shield for a corrugated structure which is also used as a coolant container. Such a fabrication would possess characteristics quite different from any of the three basic concepts reviewed here, and for certain applications could be superior. Because hybrids may produce the most desirable characteristics, thoroughness of investi-

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gations in materials, processes, and structural techniques for thick-skinned, thermal-shield, and cooled structures cannot be overemphasized.

It is understandable that the great variety of activity in structures and materials today is healthy and necessary. In fact, increased diversification is desirable, as is intensification of some of the important programs now underway. Theories on managing these vast fields suggest the need for closer coordination between the user of materials —the structural designer—and the materials supplier. Some theories propose integration of materials and vehicle development.

The marriage of the disciplines of aerothermodynamics and structures to beget a configuration introduces effects due to vehicle size. It is axiomatic that low wing loadings (W/S) will contribute to low heating rates, yet the large wing areas involved mean more total re-entry heat absorbed. Conversely, as less wing is employed in a given design, higher heating rates and lower total heat inputs occur.

Selection of wing loading for a particular application depends on a compromise among re-entry vehicle induced penalties to the booster, specific payload volume requirements, and the trade-off between structural and contents weight.

Illustrations and table on page 42 describe three examples of design emanating from the technology previously discussed.

Configuration A is a small unmanned lifting re-entry vehicle designed as a fully recoverable experimental instrument to determine the accuracies of theory. This type of vehicle would be designed to explore a wide re-entry corridor, and to be useful it would have to embody the near-future state of the art. A wing loading is specified consistent with available booster capabilities and the properties of the materials with which we have the greatest experience. The aerodynamic shape can give a wide range of lift coefficient in the high-heating region in order to maximize the flight corridor with adequate safety margins. In addition, the shape yields an L/D which would provide long-range recovery from a variety of boosted conditions. This design extends panels outward from the wing tips in subsonic flight to position the aerodynamic center in close proximity to the hypersonic and supersonic location, thus avoiding excessive longitudinal trim at high speeds and instability at low speeds. This satisfies the conditions outlined in the table on page 76. In addition, the panels increase the effective aspect ratio of the subsonic configuration.

Configurations B and C represent advanced recoverable earth-orbital systems. The large payloads specified would suggest that considerable internal volume and power are required. Configuration B employs a heat shield similar to Configuration A, but requires a more rigid structure. Configuration C is a more compact lifting body relying upon a very different construction to accommodate higher heat fluxes.

Although configurations B and C carry identical payloads at nearly identical re-entry weights, Configuration C requires less weight of total contents. This situation exists because the equipment environmental control and structural cooling functions can be a common system. Additionally, the structure can be over-designed to accommodate a malfunctioning cooling situation without severe weight penalties. The higher wing loading of Configuration C also provides a neater package on the booster. Configuration B will possess better aerodynamic properties due to its cleaner lines. The wing loading of Configuration B is noticeably greater than that of the similarly configured A model because minimum wing area in the boosted mode is important. Corridor height is not important here, because, unlike Configuration A, this vehicle can operate within a narrow band of re-entry lift coefficients near the optimum. The higher wing loading is thereby justified.

Research and development in lifting re-entry is leading to configurations along these lines. This work can also improve designs if adequate advances in materials and structures are achieved. What will improving the state of the art in structures and materials accomplish?

Imagine a ceramic composite structure similar to Configuration C such that external temperatures to 4500 F can be safely endured. In addition, if the natural temperature drop across skin face and insulation were large and an internal water cooling and insulation system could further reduce the structural temperature down to 100 F, then a unit structural weight in the vicinity of 4 lb/sq ft of wetted area might be realized. The high-temperature limit would allow more compactness than possible with Configuration C, because radii could be reduced and the vehicle volume could be scaled to more nearly approach that of the payload and internal equipment. Therefore, the structural cooling system would become more intimate with the subsystem environmental control system and the total weight of the vehicle would compound downward. Conceivably, the re-entry weight of the vehicle would be reduced 15%, or alternately the payload could be proportionately increased.

Consider another example. The emissivity of a refractory metal is improved to near unity by means of a coating that would simultaneously afford lasting oxidation and abrasion resistance. The equilibrium wall temperature for a given flight path could then be reduced as much as 250 F. A temperature reduction of this magnitude would allow a structural strength-to-weight-ratio increase, and the net result would be a 25 to 30% reduction in structural weight.

It would appear, then, that we now possess a good understanding of the physics of lift re-entry from earth orbits and are proceeding properly towards increasing this knowledge. However, we desire more correlating aerodynamic information, so vital to establish design configurations. In addition, much work remains to be done on superorbital-re-entry heating.

Material and structural applications are the areas where we must progress most rapidly—where we can profit most by general improvement in the state of the art. Much work today is in fact directed toward fixes for the faulty properties of the materials that we know most about. This has been the first order of business, but emphasis on new techniques is vital. Also, confidence is prevalent that relatively small extensions of today's knowledge of aerodynamics and structures will result in workable vehicle

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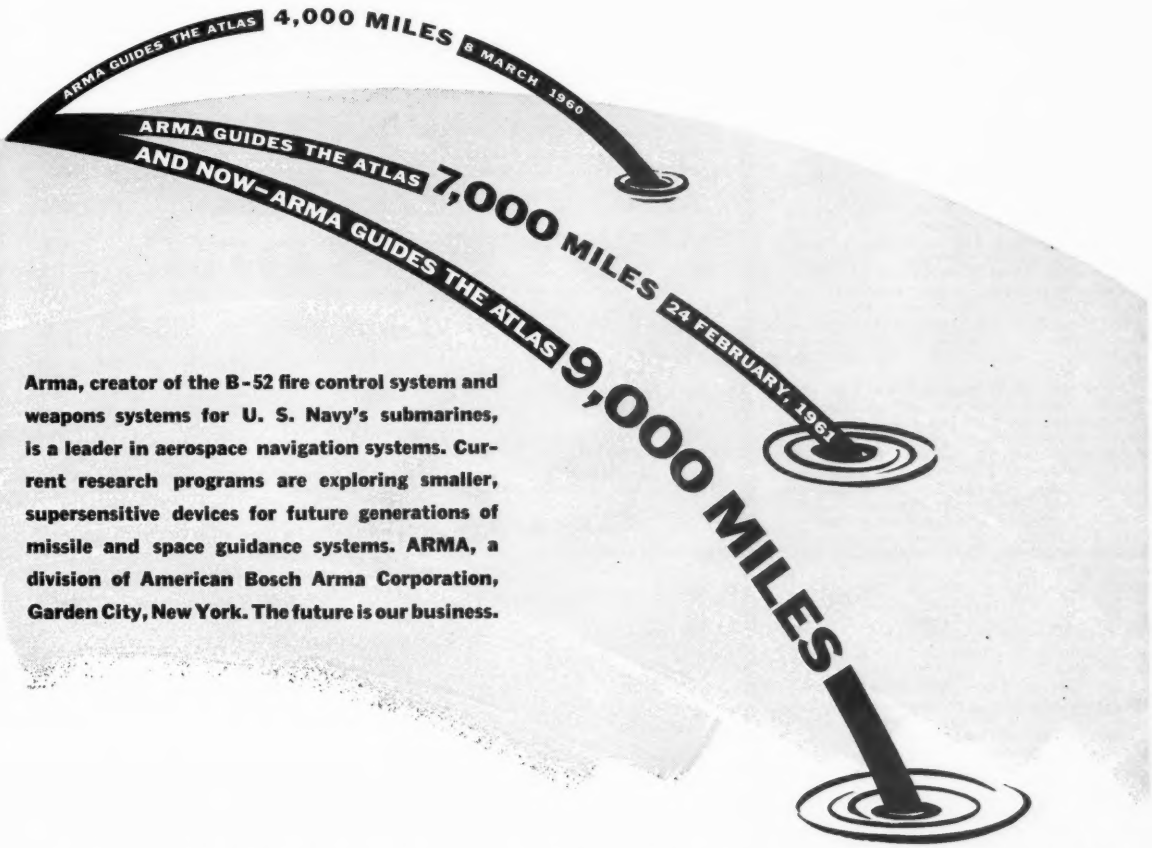
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designs.

The diversification and magnitude of research and development on lifting re-entry is indeed immense. Much of the nations resources, in and out of the industry, as well as those of government, are involved in programs necessary to development of the lifting re-entry concept. For this reason there is a need for more exacting management of applied research and development programs, individually and collectively.

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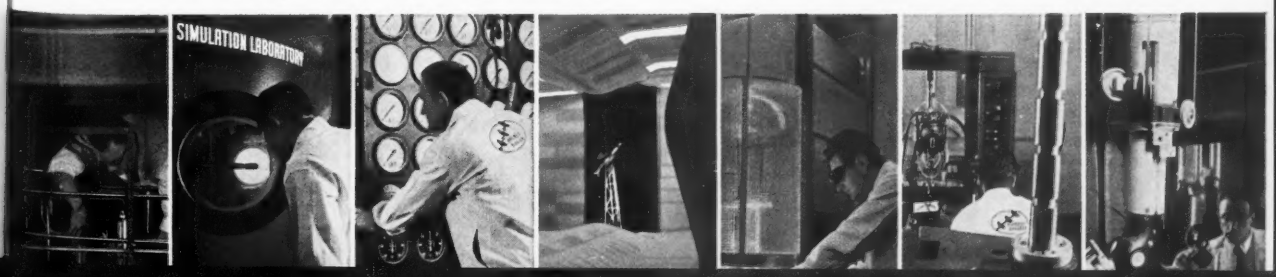

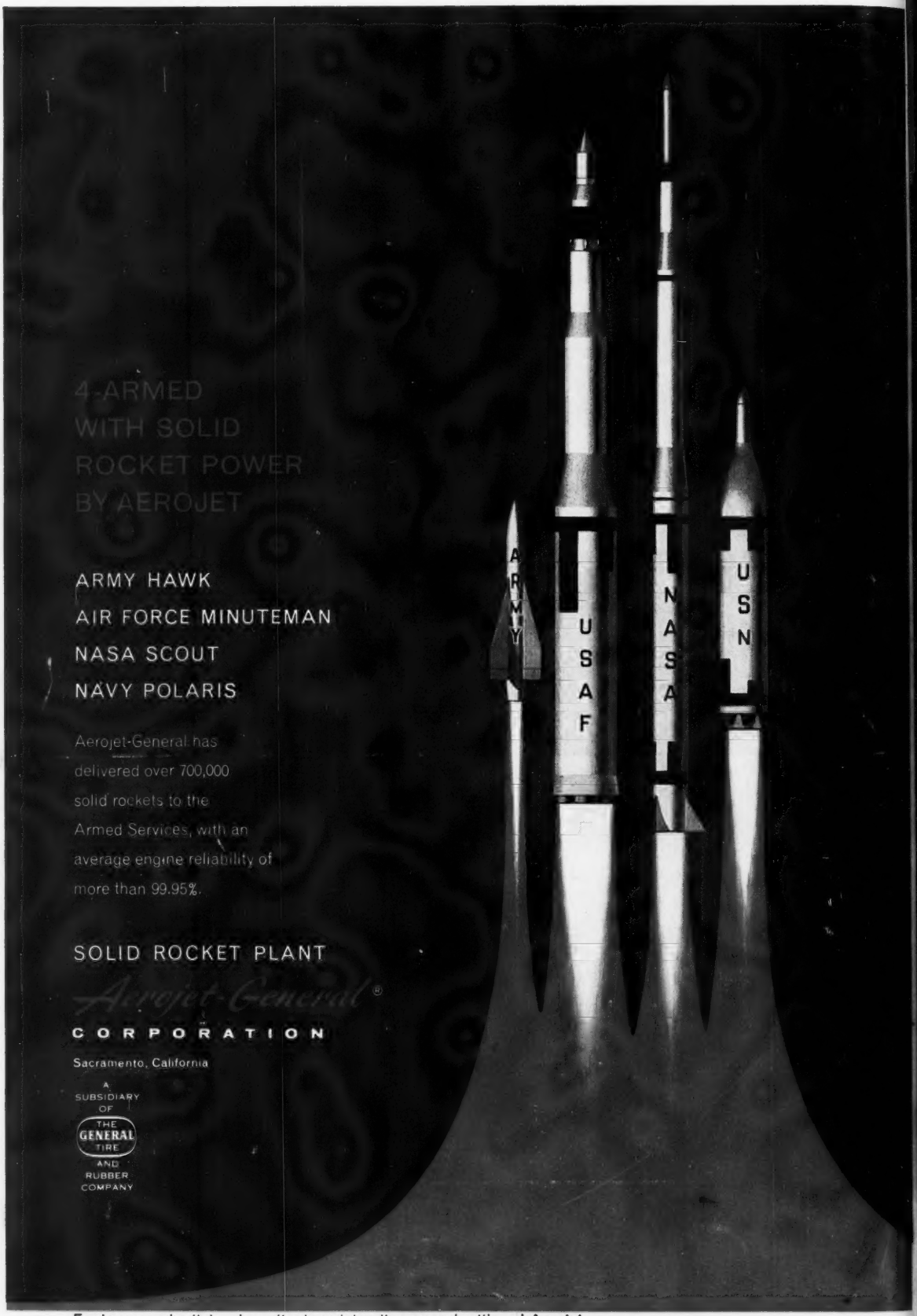

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